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UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF ENTOMOLOGY

FOREST INSECT INVESTIGATIONS

TEMPERATURES AFFECTING THE WESTERN PINE BEETLE

by

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Forest Insect Laboratory
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INTRODUCTION

Among the factors which control the natural activity of bark-beetles, temperature is perhaps the most important. The conditions under which these insects will feed, develop and multiply occur within a comparatively small range of temperatures. Above or below this range normal activity ceases, and as temperatures rise or fall the points are soon reached where complete mortality occurs.

This relation of temperature to insect activity and mortality has important economic aspects in the case of certain barkbeetles that cause serious losses to timber. The effect of seasonal temperatures in stimulating activity and extending the period of development may have much to do with the abundance or scarcity of barkbeetles in forest regions. High and low temperatures may also cause direct killing of the broods. It was discovered some years ago that the degree of heat produced by the exposure of the infested bark to sunlight would result in effective mortality of Dendroctonus broods. This principle has been applied in the solar-heat method of control, which has been successfully used on barkbeetle-control projects where conditions are suitable. It has long been suspected that low freezing temperatures were the cause of high mortality of Dendroctonus broods. One case of this kind occurred in the vicinity of Bend, Oregon, in December 1924, when unusually low temperatures of from 20° to 25° below zero occurred in yellow pine areas. A study of the situation made by Mr. A.J. Jaenicke of the Forest Service indicated that the mortality ranged from 25 to 80 per cent. A control project that had been planned against an epidemic of the western pine beetle was found to be unnecessary because of the extensive mortality of the broods following this cold spell.

Since 1920 studies of the effect of both high and low temperatures on western pine beetle broods have been carried on, under both field and laboratory conditions, by the Bureau of Entomology. The object of this report is to summarize the information that has been accumulated in this work, in order that it may be made available for further study of the problem.

BROOD STAGES INCLUDED IN STUDIES

Parent adults of the western pine beetle attack through the outer bark and extend their egg-galleries in the inner bark of yellow pine. The young larvae develop in the outer bark until they are nearly half-grown, then work their way into the outer bark, where the remainder of the life-history period occurs. Control methods, including solar heat, depend almost entirely upon killing the brood stages, consisting of larvae, pupae and new adults in the outer bark. This is because the infested trees are difficult to locate before the brood stages are well advanced, and the ease with which the bark may be peeled increases with the advance of brood development. The great majority of the broods overwinter as half- to full-grown larvae in the outer bark, and it is these stages that we can expect to find killed by low winter temperatures.

Because of these points and the ease with which the material can be handled, the studies were confined mainly to the larvae, pupae and new adults in their natural environment in the outer bark. A few tests, however, were made on the live insects exposed to air temperatures without the natural protection of the outer bark.

In these studies records of bark temperatures were kept by readings of mercurial thermometers imbedded in the bark to a depth where the infesting broods were found (see Chart No. 1). The record secured, therefore, applies only to environmental temperatures, and no attempt was made to record temperatures within the body of the insect itself.

EFFECT OF HIGH TEMPERATURES

LARVAE

It was discovered in June, 1919, during the course of control work in Sequoia National Park that complete mortality of broods occurred in infested bark that had been removed from the log and left unburned on the ground where it was exposed to the sun's rays at midday. In order to determine the temperature conditions necessary to produce this result a series of tests and records was carried out by Mr. J.E. Patterson and the writer at Ashland, Oreg., and Northfork, Calif., during the season of 1920. The results indicate that

mortality due to heat does not result from bark temperatures below 95° F., that

from 40 to 90 per cent of the brood is killed under prolonged exposure to bark temperatures ranging from 100° to 115° Fahr., and that

exposure of two or three hours after the bark reaches a temperature of 115° results in 100% portality. Brief exposures of less than one hour at bark temperatures of 120° and over are approximately 100% fatal.

It was found that when the bark was removed from the log and exposed to the direct rays of the sun it reached temperatures of 100° to 132° when the air temperatures in the shade ranged from 80° to 95° Fahr. (Charts 12, 13 and 14).

In these tests the factor of relative atmospheric humidity was not taken into consideration. Under the conditions of the test each individual of the brood was enclosed in a cell excavated by the larva in the outer bark. Atmospheric conditions affecting the larva cannot therefore be considered comparable to those of the open air outside of the bark. It is evident that moisture content of the bark is the most important controlling factor of humidity in the insect's environment.

By removing the larvae from the bark and subjecting them to high temperatures in sealed containers where evaporation was prevented, from 5 to 8 more degrees of heat were necessary to produce the same effects of paralysis and mortality than where larvae were exposed to rapid evaporation in warm circulating air. These results are shown in Table No. 1. In general it was found that with the larvae in sealed containers, which corresponds to conditions in the outer bark, paralysis sets in after brief exposures at 108° to 110°; mortality occurs between 115° and 118°; and no larvae survived temperatures above 118° F. These results correspond closely to those obtained at similar temperatures in the infested bark.

PUPAE AND ADULTS

These two stages were included in a number of the above tests with infested bark. It was found that these do not survive the high temperatures that are fatal to half- to full-grown larvae.

TEMPERATURES UNDER WHICH LARVAE ARE ACTIVE

The range of temperatures governing activity was observed by removing live larvae from the bark and watching them while exposed in open containers to varying air temperatures. The only gauge of activity that could be used under these conditions was movements of the larvae when undisturbed and when touched with a camelshair brush. A larva when removed from its gallery in the bark will, under normal temperatures of from 50 to 100 degrees, keep up more or less continuous movement of the body and maintain a "doubled-up" position, with head and anal end close together. Dead or paralyzed larvae lie with the body extended.

In general, normal activity appears to occur within a range of 50 to 100 degrees Fahr. At temperatures a few degrees above or below this point larvae become noticeably sluggish. Paralysis from heat occurs between 105 and 110 degrees, and dormancy from cold sets in between 45 and 40 degrees (Tables 1, 6 and 7).

EFFECT OF LOW TEMPERATURES

METHODS AND EQUIPMENT USED IN TESTS

In the more important tests with low temperatures, as in the solar heat records, bark temperatures were used as the determining factor affecting the brood in the outer bark, being recorded by an imbedded mercurial thermometer. Thermocouples were tried, but were found to offer no advantages over the more simple type of thermometer, which could be set up and read conveniently.

Low temperatures were controlled by the use of a specially-designed brine tank cabinet with a Frigidaire compressing unit. This provided for two 10x16x24 air compartments in an insulated brine tank cooled by a carbon bisulphid coil, and compressor operated by a 1/3-horse-power electric motor. This apparatus would produce air temperatures in the compartments as low as -24° F. The rate at which the temperature could be lowered in the air compartments was controlled by cutting off and turning on the motor. This apparatus was installed in the Bureau of Entomology Laboratory at Stanford University, where all the low-temperature tests of infested bark sections were conducted.

The infested bark sections used in the tests were from one to two square feet in size. These were placed in the air compartments, where at the beginning of each test the temperature was the same or slightly below that of the laboratory. The temperature within the compartments was then lowered at the rate decided upon until the bark temperatures had reached the desired minimum. Sections were removed from the cabinet at determined intervals of temperature and placed in the laboratory under normal room temperatures. After 24 hours or more the bark was broken up, the brood removed, and a count made of the live and dead individuals. In doubtful cases the brood was kept under observation for several days or longer until dead individuals could be unmistakably distinguished from those showing evidence of recovery.

When exposed larvae were used in tests they were placed in open pasteboard boxes, and temperature readings were taken from thermometers placed with bulbs in box at the same level as the larvae.

TESTS WITH LARVAL STAGES OF BROOD

1. Rapid Lowering of Bark Temperatures from 45 to -18° F. Test No.1

The bark temperatures in this test were lowered from 45 to -18 degrees F. within 48 hours. In addition to a check, bark sections were removed at each 5-degree interval below 20 degrees. At -18 degrees the motor was stopped and the remaining sections in the cabinet allowed to warm back slowly. One section was removed when the temperature had warmed back to 20 and another at 35 degrees. The results, which are included in Table No. 2 and Chart No. 2, show the following critical temperatures:

Temp. F.	Mortality
45 to 5	0
0	-18.2%
-5	73.8"
-10	100. "

The mortality in the sections that were allowed to warm back slowly to normal temperatures was found to be 100%. These results indicate that temperatures between 0 and -10 degrees are fatal, and that below -10 the mortality is complete, regardless of whether the return to normal temperatures is sudden or gradual.

2. Gradual Lowering of Bark Temperatures from 48°to -15° F. Test No.2.

In this test the bark temperatures were lowered gradually from 48 to -15 degrees through a period extending over nine days. The same procedure of removing bark sections at intervals of 5 degrees and the gradual return to normal temperatures was followed as in Test No. 1. The results are shown in Table 5 and Chart 3.

Temp. F.	Mortality
48°to 5°	0
-1	18%
-5	79"
-14	100"

Through an error no bark section was removed at -10°, but the high mortality recorded at -5° indicates that none survived -10°. These results indicate that the slow lowering of temperature to sub-zero stages neither increases nor lowers the resistance of the larvae to critical temperatures between 0 and -10 degrees.

5. Larvae Removed from Bark and Exposed to Air Temperatures. Tests 6 and 7.

The results of the first two tests raised the question as to whether the protection and insulation afforded by the outer bark enabled the larvae to resist lower temperatures than when they were exposed directly to the air. This point is shown by Test No. 6, in which larvae recently removed from the bark and placed in open pasteboard containers were run through a range of temperatures from 65 to -8 degrees F. The following mortalities resulted (see Tables Nos. 7 and 8, Chart No. 8):

Temp. F.	Mortality
65 to 10 F.	0
5	18%
0	18
-5	58
-8	100

These results indicate that the larvae are little if any more susceptible to absolute temperatures when exposed to air than when in the bark.

Tests 6 and 7 were also used to observe the behavior of larvae at temperatures above the freezing point. It was found that activity slowed down as the point of 50° was reached, dormancy set in between 45°and 40°, and that below these points very little change could be observed until a temperature around 15° to 10° above zero was reached. At this point the larvae became rigid, hard, and took on a peculiar white color. However, practically all were able to recover from this condition if brought back to normal temperatures, until after they had been exposed to temperatures around zero. Beyond this point mortality increased, and was complete at -8°.

4. Time Required to Produce Mortality When Suddenly Exposed to Fatal Temperatures. Tests 3 and 4.

In Test No. 3, five groups of 20 larvae each in open cardboard containers were taken from a room temperature of 70° and placed in the cabinet, where the air temperature was held at -15°. One lot was removed after ten minutes and one at each ten-minute interval following until all were out. After two days it was found that 17 in the first lot were still alive after ten minutes' exposure, five after 20 minutes, while all were dead in the three subsequent lots.

In Test No. 4, four lots of 20 each were exposed in the same manner to a temperature fixed at -9°. These were removed at 15-minute intervals. Six larvae survived after 15 minutes' exposure, three after 30 minutes, and all were dead in the lots taken out after 45 and 60 minutes.

These results (see Tables 3 and 4) indicate that an exposure of approximately 30 minutes is necessary to produce complete mortality when larvae are suddenly exposed to a temperature below the point that is ordinarily fatal. However, when the broods have been gradually chilled down to the range of critical temperatures, it is apparent that the effect is almost immediately fatal, as shown by the mortality found in bark sections removed from the cabinet as soon as the fatal temperatures were reached.

5. Broods Overwintering Where Regional Winter Temperatures Fall Below Zero. Test No. 5

All the material used in the foregoing tests was collected at Northfork, Calif., where winter temperatures in the field seldom fall below 20° F. As these broods are never subjected to extreme low temperatures in their natural environment, there is a possibility that they did not develop greater resistance because of regional influences.

Through the cooperation of Mr. J.C. Evenden of the Bureau of Entomology at Coeur d'Alene, Idaho, about 25 square feet of infested bark was collected in Northern Idaho in January 1927 and shipped to Stanford University, Calif. This bark contained broods which had been in overwintering condition for several months and had been exposed to field temperatures as low as -10°. A series of bark sections were carried through the same range of temperatures as in Test No. 1 (see Table No. 8, Chart No. 4).

Temp. F.	Mortality
55 to 10	0
5	16%
0	0
-5	49
-10	76
-12	89
-18	94.9
-18	100.

While mortality occurred within the same range of critical temperatures as in the Northfork material, considerable survival was found at temperatures below 10°, and approximately 10° more of cold were required to produce complete mortality. These results indicate that the overwintering larvae are capable of developing greater resistance in cold than in warm regions, but that this resistance does not extend the range of fatal temperatures more than 10°.

6. Broods Transferred Directly from Field to Freezing Cabinet While in Overwintering Dormant Condition. Test No. 10

In the material, both from Northfork and from Coeur d'Alene, that was used in the foregoing tests, the transfer was not made directly from the field to the freezing cabinet. The infested bark was held for a few days in the laboratory, which gave some opportunity for the larvae to become active. The object of Test No. 10 was to transfer the bark, with broods still in overwintering condition, directly from field conditions to the freezing cabinet. The material used was collected at Northfork in December, and in the transfer to the laboratory was not exposed to a temperature higher than 50°. It was therefore considered that the broods were in the same dormant condition when they entered the test as they were in the field.

It was found in the check that a mortality of from two to four per cent had already developed in the field. This low mortality is frequently found in the advanced larval stages, and in this case could not have been due to freezing, as the winter temperatures on the Northfork area did not drop lower than 20° F. up to the time that the bark was collected.

The following mortality developed in bark run through the same range of temperatures as Test No. 1 (see Table No.10, Chart No.7):

Temp. F.	Mortality
40 to 5	2 to 3%
-3	31
-5	60.7
-10	100
-15	100

7. Broods in Active Developing Condition When Transferred to Freezing Cabinet (Test No. 11)

As a contrast to Test No. 10, infested bark containing larvae in the young to half-grown stages was kept in the laboratory until the broods had developed nearly to the full-grown stage. Bark sections were then transferred from laboratory temperatures around 60 to 70 degrees to the freezing cabinet and subjected to the same range of temperatures as in Test No. 1 (see Table No. 11, Chart No. 8):

Temp. F.	Mortality
45 to 5	2.5 to 4%
0	13%
-5	57
-8	100
-10	100

The results of these tests, 10 and 11, indicate that larvae in the active developing condition are little if any more susceptible than dormant overwintering larvae, if the broods are collected from the same general region.

8. Broods Subjected to Daily Changes of Temperature, Ranging from 25° to 70° Before Exposure to Sub-Zero Stages. Test No. 12

In all the foregoing tests the larvae were lowered to temperatures below 40° and were not brought back to active temperatures until after they had been exposed to the critical points below zero. This differs from the natural temperature changes in the field under which the broods prepare themselves for the overwintering condition. In most of the yellow pine belt the daily changes of temperature in the fall are marked by warm days and cold nights. Until the more severe cold of winter sets in, the minimum temperature at night is well below freezing, while during the day the maximum may go considerably above 60°.

In this test an effort was made to simulate this effect by exposing larvae in the bark to temperatures ranging from 25° to 70° during each 24-hour period. After this exposure had been repeated during a period of six days, the bark was carried down through the same range of critical temperatures as in Test No. 1 (see Table No. 12, Chart No. 9):

Temp. F.	Mortality
70 to 10°	1% to 2%
5	17
0	16
-5	62
-7	85.5
-10	100

This test indicates that the larvae do not develop any greater resistance as a result of brief exposures to temperatures that produce dormancy with intermittent periods of activity. This result is at direct variance with that secured from a preliminary test with Dendroctonus monticolae larvae. It was found that these larvae, if brought back to warm temperatures after exposure to 25°, will start to empty the alimentary canal of its contents. The observations on this species are not at all conclusive, but it was found that individuals of a brood that had gone through this process of preparation, would withstand 10 more degrees of cold than those which were directly exposed to sub-zero temperatures.

BROODS IN PUPA STAGE (Test No. 13)

Infested bark in which the broods had transformed to pupae was subjected to a series of exposures similar to Test No. 1 (see Table No. 13, Chart No. 10):

Temp. F.	Mortality
65° to 11°	0
6	16%
0	26
-5	99
-8	100
-10	100

These results indicate that pupae are slightly less resistant than larvae, as shown by practically complete mortality at -5°.

BROODS IN NEW ADULT STAGE (Test No. 14)

The material used in testing the resistance of this stage to low temperatures consisted of young adults still in the outer bark. The great majority of them had become fully colored, and part of the brood had started to emerge. Bark sections were lowered through the same range of temperatures as in Test No. 1 (see Table 14, Chart No. 1):

Temp. F.	Mortality
60° to 20°	0
15	12%
10	90
5	97
0	95.6
-5	100
-10	100

In a similar test shown in Table 15, small groups of adults were kept under observation as they were removed from the freezing cabinet. This test shows that the range of critical temperatures occurs above zero, but due to limited material does not define the limits of the range as well as the preceding test.

These results show that adults are susceptible to higher temperatures than the larval and pupal stages, and that the range of critical temperatures occurs between 15 and -5 degrees.

PROBABLE RESULTS OF LOW TEMPERATURES IN THE FIELDS UPON OVERWINTERING BROODS

Records of brood mortality in infested trees that can be attributed to freezing have been secured but rarely. It is evident that in regions where winter temperatures fall well below zero, either the temperatures in the bark on standing infested trees do not go so low as they do in the surrounding atmosphere, or else the barkbeetles are capable of developing a resistance to temperatures far below that indicated by the foregoing tests.

That the first assumption explains the case, at least in part, is borne out by two series of records made by J.C. Evenden and H. J. Rust at Coeur d'Alene, Idaho, in January 1927 and again in January 1928. During periods of sub-zero weather thermometers were placed in the bark on the north and south sides of an infested tree and on all four sides outside of the bark. Readings were taken hourly during a period of 28 hours. At the lowest point when the readings were started the air temperature was -6, while the bark temperatures were 6 and 4. This shows a difference of 12 and 10 degrees between the air and bark temperatures. This dispersion decreased as the air temperature rose, and the two sets of readings were close together when the air temperature reached 12 degrees. No mortality occurred in the broods, which would be expected, since critical temperatures were not reached in the bark.

As the infested bark is in contact with the moist sapwood of the tree, which in turn connects with the root system in the soil, there is undoubtedly a reserve of warmth which prevents rapid falling of bark temperatures. It would appear that only prolonged periods well below zero could chill the bark sufficiently to produce critical temperatures for the broods.

Further records of the dispersion between air and bark temperatures are necessary before we can know when th expect mortality of western pine beetle broods as a result of unusually low regional temperatures.

EFFECT OF LOW TEMPERATURES ON PARASITES AND PREDATORS OF THE WESTERN PINE BEETLE

Predators, mainly larvae of Temnochila virescens and Thanasimus nigriventris, were found occasionally in the bark sections examined in a number of the tests. The larvae of a chalcid parasite were also found in some of the material and adults of Aulonium longum. Mortality of these insects was noted, but none of them occurred in sufficient numbers to give a satisfactory index as to fatal temperatures. Such records as were secured, however, indicate that the predatory larvae and Aulonium adults are killed at temperatures between 10 degrees and zero. None of them survived temperatures fatal to the western pine beetle. The parasitic larvae, however, survived all temperatures experienced in the tests. These larvae, after an exposure to -20° F., recovered when brought back to normal temperatures, resumed development and matured to the adult stage.

TABLE NO. I

EFFECT OF HIGH TEMPERATURES ON EXPOSED LARVAE

Temp. Fahr.	Lot 1	Lot 2
	100 larvae removed from bark and divided into 5 groups of 20 each in open pasteboard containers. These were exposed at varying heights over an electric plate under free circulation of air and evaporation.	100 larvae removed from bark and divided into 5 groups of 20 each in glass vials sealed with paraffin. Vials were submerged in water which was heated until temperature in vials reached 120 degrees F.
70—90	Normally active	Normally active
90—95	Maximum activity	Maximum activity
95-100	Slight activity; paralysis after prolonged exposure	Activity decreases
100-105	Paralysis after brief exposure: complete mortality results after 30 minutes' exposure at 105	Slight activity continues up to 105
105-110	Fatal after brief exposures	Paralysis occurs at 108 to 110°; larvae paralyzed from brief exposures will recover after return to normal temperatures
110-115	Fatal after brief exposures	Paralysis occurs after 20 minutes' exposure; larvae do not recover if returned to normal temperatures
115-120	Fatal after brief exposures	Complete mortality occurs between 115 and 118°; no survival at temperatures above 118°

4a+5

D. BREVICOMIS - TEST #12

MORTALITY OF LARVAE IN ACTIVE CONDITION IN YELLOW PINE BARK SUBJECTED TO DAILY CHANGES OF TEMPERATURE RANGING FROM 74 TO 24° F. AND THEN LOWERED TO -11° F.

Material collected at Northfork, Calif., December 1927 and kept under field conditions during January. Bark transferred to laboratory under active temperatures about two weeks before test was started.

Date 1928	Hour	Temp.F. of Bark in Room	Temp.F. of Bark in Cabinet	Bark Section Removed	Date of Cutting: Test	D.brevicomis Larvae Alive	D.brevicomis Larvae Dead	D.brevicomis Larvae Mort.	T.nigriventris larvae Alive	T.nigriventris larvae Dead
Feb.14:	8:30 am:		24°#							
	5:00 pm:	68°								
	8:30 pm:		23+							
Feb.15:	8:30 am:		24#							
	3:30 pm:	72								
	8:30 pm:		20+							
Feb.16:	8:30 am:		26#							
	3:30 pm:	74		10-check	2/15/28	340	7	2%		
	8:30 pm:		23+							
Feb.17:	8:30 am:		26#							
	3:30 pm:	74								
	8:30 pm:		25+							
Feb.18:	8:30 am:		25#							
	3:30 pm:	72								
	8:30 pm:		26+							
Feb.20:	7:00 am:		45							
	11:30 am:		25	1	2/23/28	126	2	1.5	1	
	1:45 pm:		20	2	"	100	1	1		
	2:30 pm:		15	3	"	98	2	2		
	4:30 pm:		10	4	"	105		0		
	8:15 pm:		5	5	"	110	2	1.7		
Feb.21:	7:00 am:		10							
	1:30 pm:		0	6	"	88	77	16		
	4:00 pm:		-5	7	"	46	75	62		
	5:30 pm:		-7	8	"	22	120	85.5		
	8:30 pm:		-9	9	"		100	100		
	9:40 pm:		-11	10	"		100	100		

- Bark removed from cabinet
\+ - " placed in "

Table No. 12

Dendroctonus brevicomis - Test No. 1. Mortality of half- to full-grown larvae in yellow pine bark subjected to temperatures ranging from 45° to -16° Fahr. Bark was collected in field at Northfork, Calif., in December 1925 and kept in laboratory (50° to 70° Fahr.) before test was started

Date 1926	Hour	Temperature Degrees Fahr. Air	Temperature Degrees Fahr. Bark	Bark Section Removed	Date of Cutting Test	Dendroctonus brevicomis Larvae Alive	Dendroctonus brevicomis Larvae Dead	Dendroctonus brevicomis Larvae Mortality %	Thanasimus mimi- ventris Larvae Alive	Thanasimus mimi- ventris Larvae Dead	Temnochila virescens Larvae Alive	Temnochila virescens Larvae Dead	Chalcididae Parasitic Larvae Alive	Chalcididae Parasitic Larvae Dead	Aulonium longum Adults Alive	Aulonium longum Adults Dead
Jan.4	11:20 a.m.	36	46	Check	Jan. 7, 1926	185		0	2		3		4		2	
	12:15 p.m.	25	34													
	1:20 p.m.	22	28													
	2:15 p.m.	18	25	1a	Jan.5, 11 a.m.	23		0								
	3:00 p.m.	16	22													
	3:25 p.m.	14	20	2a	Jan.5, 2 p.m.	11		0								
	3:45 p.m.	10	18													
	4:30 p.m.	8	15	1	Jan.5,24	33e: 10 pu:		0					1		2	
	5:15 p.m.	6	13													
	7:00 p.m.	-1	7													
	7:45 p.m.	-8	5	5	Jan.6	27		0								
	8:45 p.m.	-6	3													
	9:45 p.m.	-8	-0	2	Jan.6 79 2 22	146	33	18.2								
	10:00 p.m.	-9	-7*													
Jan.5	6:45 a.m.	-2	2													
	7:45 a.m.	-4	0													
	8:30 a.m.	-8	-1													
	9:45 a.m.	-9	-8													
	10:45 a.m.	-12	-5	6	Jan. 6 18	52	150	73.8			2					
	11:45 a.m.	-14	-6													
	12:45 p.m.	-16	-10	7		7	248	97			3			1		
	2:25 p.m.	-18	-12													
	4:25 p.m.	-20	-15	8	Jan. 6 19		168	100			1		2	2		
Jan.6	8:40 a.m.	-22	-18*	4			161	100					1			
Jan.7	8:15 a.m.	2	3													
	2:40 p.m.	7	8													
Jan.8	8:15 a.m.	18	20													
	4:00 p.m.	24	26	9			97	100			1		1			
Jan10	9:15 a.m.	40	42													
	4:20 p.m.	48	44	10												

* Out off notch of freezing cabinet

\# Started " " "

Table No. 2

D. BREVICOMIS - TEST NO. 2

MORTALITY OF HALF- TO FULL-GROWN LARVAE IN YELLOW PINE BARK
SUBJECTED BY SLOW STAGES THROUGH A RANGE OF TEMPERATURES FROM 45 TO -10° FAHR.
MATERIAL COLLECTED AT NORTHFORK, CALIF., DECEMBER 1926
MORTALITY OF PREDATORS ALSO RECORDED

Date 1926	Hour	Temperature in Cabinet ° Fahr: Air	Bark	Bark Section Removed	Date of Cutting Test	Dendroctonus brevicomis Larvae: Alive	Dead	Mortality %	Thanasimus nigriventris Clerid Larvae: Alive	Dead	Temnochila virescens Trogositid Larvae: Alive	Dead	Chalcididae Parasitic Larvae: Alive	Dead	Aulonium longum Adults: Alive	Dead
Jan.11	10:30 a.m.	46														
	12:30 p.m.	32	42°													
	2:10 p.m.	22	34													
Jan.12	8:30 a.m.	30	32													
	10:30 a.m.	18	28													
	12:30 p.m.	10	20°	1	Jan.13	100		0	2							
Jan.13	8:10 a.m.	26	26													
	9:45 a.m.	15	20													
	11:10 a.m.	9	16°													
	4:25 p.m.	12	15	2	Jan.20	103		0	3							
Jan.14	8:05 a.m.	20	22													
	10:20 a.m.	10	16													
	11:20 a.m.	8	15°													
	2:40 p.m.	8	10													
	4:30 p.m.	9	10	3	Jan.20	55		0		2						
Jan.15	8:00 a.m.	16	19°													
	12:25 p.m.	0	8°													
	2:45 p.m.	2	5	4	Jan.21	165		0		1						
Jan.16	10:20 a.m.	12	15													
	12:25 p.m.	2	13°													
Jan.17	8:00 a.m.	16	17													
	10:00 a.m.	7	15													
	12:00 m.	0	8													
	3:00 p.m.	-8	3													
	4:30 p.m.	-10	-1°	5	Jan.18	105	23	30		2						
Jan.18	8:00 a.m.	2	5													
	11:00 a.m.	-8	0													
	1:30 p.m.	-10	-3													
	2:15 p.m.	-10	-5	6	Jan.19	34	138	79	1	3						
	3:45 p.m.	-12	-6°													
Jan.19	8:00 a.m.	2	5													
	12:45 p.m.	-11	-7													
	8:30 p.m.	-20	-14	7	Jan.20		153	100		4						
	9:30 p.m.	-21	-15°													
Jan.20	7:30 a.m.	-10	-7													
	4:30 p.m.	-10	-13°													
Jan.21	8:00 a.m.	-2	0													
Jan.22	8:30 a.m.	2	6													
Jan.24	5:00 p.m.	30	34													
Jan.25	8:00 a.m.	35	39	8			203	100		8						
Jan.26	12:30 p.m.	44	47													

° Motor started

* Motor cut off

Table No. 3

TEST NO. 3

D. BREVICOMIS. MORTALITY OF FULL-GROWN LARVAE REMOVED FROM BARK AND EXPOSED FOR PERIODS FROM 10 TO 50 MINUTES TO AN AIR TEMPERATURE OF -15 DEGREES F.

Material collected at Northfork, Calif., December 1926. 100 full-grown larvae were removed from bark January 20 1927 and placed in open cardboard containers in lots of 20 each. These were taken from a laboratory temperature of 70° and placed in freezing compartment where the air temperature registered -15° F.

Date	Lot #1	Lot #2	Lot #3	Lot #4	Lot #5
Jan. 20 1:20 p.m.	Placed in Cabinet Temp.-15 F.	Placed in Cabinet Temp.-15 F.	Placed in Cabinet Temp.-15 F.	Placed in Cabinet Temp.-15 F.	Placed in Cabinet Temp.-15 F.
1:30 p.m.	Remvd.fm. cabinet Temp.-14 F. All frozen				
1:40 p.m.		Remvd.fm. cabinet Temp.-14 F. All frozen			
1:50 p.m.			Remvd.fm. cabinet Temp.-14 F. All frozen		
2:00 p.m.				Remvd.fm. cabinet Temp.-14 F. All frozen	
2:10 p.m.					Remvd.fm. cabinet Temp.-14 F. All frozen
2:45 p.m.	All active	All dormant	All dormant	All dormant	All dormant
Jan. 22 8:40 a.m.	17 alive - 3 dead	5 alive -15 dead	20 dead	20 dead	20 dead
Jan. 24 9:15 a.m.	16 alive - 4 dead	5 alive-15 dead	20 dead	20 dead	20 dead

Table No. 4

D. BREVICOMIS - TEST NO. 4

MORTALITY OF FULL-GROWN LARVAE REMOVED FROM BARK AND EXPOSED FOR PERIODS OF FROM 15 TO 60 MINUTES TO AN AIR TEMPERATURE OF -9° F.

Material collected at Northfork, Calif., December 1926. 80 full-grown larvae were removed from bark January 21 1927 and placed in open cardboard containers in lots of 20 each. These were taken from an air temperature in the laboratory of 70 degrees and placed in freezing compartment where the air temperature registered -9°F.

Date	Lot #1	Lot #2	Lot #3	Lot #4
Jan. 21 2:30 p.m.	Placed in Cabinet Temp. -9 F.	Placed in Cabinet Temp. -9 F.	Placed in Cabinet Temp. -9 F.	Placed in Cabinet Temp. -9 F.
2:45 p.m.	Removed; all frozen			
3:00 p.m.	All thawed out; still dormant	Removed; all frozen		
3:15 p.m.			Removed; all frozen	
3:30 p.m.				Removed; all frozen
4:30 p.m.	10 active; 10 dormant	2 active; 18 dormant	All dormant	All dormant
Jan. 22 8:20 a.m.	6 alive; 14 dead	3 alive; 17 dead	All dead	All dead
12:10p.m.	6 alive; 14 dead	3 alive; 17 dead	All dead	All dead
Jan. 24 8:45 a.m.	6 alive; 14 dead	3 alive; 17 dead	All dead	All dead
Jan. 25 8:30 a.m.	6 alive; 14 dead	3 alive; 17 dead	All dead	All dead

Table No. 5

D. BREVICOMIS - TEST NO. 5

MORTALITY OF HALF- TO FULL-GROWN LARVAE IN YELLOW PINE BARK SUBJECTED TO TEMPERATURES RANGING FROM 55 TO -18° F.

Bark collected at Coeur d'Alene, Idaho, January 1927, with broods in overwintering condition. Mortality of Aulonium also recorded.

Date	Hour	Temp. in Cabinet: Air	Bark	Bark Section Removed	Date of Cutting: Test	Dendroctonus brevicomis Larvae: Alive	Dead	Mort. %	Aulonium longicorn gum: Alive	Adults: Dead
Jan.28	3:00 p.m.	48	55							
	5:00 p.m.	24	34							
Jan.29	9:00 a.m.	32	34							
	11:00 a.m.	18	30							
	12:00 m.	12	25	#5	2/2/27	112		0	66	
	3:00 p.m.	-2	7							
	4:00 p.m.	-6	4	#2	2/2/27	61	12	16.4%	3	
	4:40 p.m.	-8	1							
	5:00 p.m.	-9	0	#1	1/31/27	119		0	5	
	7:00 p.m.	-14	-5	#6	2/ 1/27	25	23	49	2	1
	7:50 p.m.	-16	-7							
	8:50 p.m.	-18	-10	#7	1/31/27	25	81	76	1	2
Jan.31	8:30 a.m.	12	16							
	11:00 a.m.	0	10							
	2:00 p.m.	-6	0							
	4:20 p.m.	-8	-2							
	11:00 p.m.	-20	-12	#3	2/ 1/27	7	56	89		
Feb. 1	8:00 a.m.	-22	-18	#8	2/ 2/27	11	207	94.9		
	10:25 a.m.	-24	-18	#4	2/ 2/27		67	100		22

Table No. 5

Table XII

D. BREVICOMIS - TEST NO. 6

CONDITION AND MORTALITY OF HALF- TO FULL-GROWN LARVAE REMOVED FROM YELLOW PINE BARK AND EXPOSED TO AIR TEMPERATURES RANGING FROM 65 to -8° F.

Material collected at Northfork, Calif., December 1926; larvae removed from bark February 10 1927. 550 larvae were separated into 11 lots of 50 each and placed in open pasteboard containers. Temperature readings in freezing cabinet were taken with bulb of thermometer at same level as larvae in pasteboard containers. Condition of larvae at time of removal from cabinet was noted.

Date Feb. 1	Hour	Temperature in Box Fahr.	Lot Number Removed	Condition of Larvae when Removed	Subsequent Mortality Date	Alive	Dead	%
Feb.11	9:10 a.m.	65	1	Active	2/15/27	50		0
Feb.11	10:35 a.m.	45	2	Mostly active; few sluggish	2/15/27	49	1	2
	11:10 a.m.	40	3	Dormant	2/15/27	50		0
	11:45 a.m.	35	4	"	2/15/27	50		0
	5:15 p.m.	20	5	"	2/15/27	50		0
	4:30 p.m.	15	6	"	2/15/27	50		0
	5:00 p.m.	10	7	Dormant; frozen rigid	2/15/27	50		0
Feb.12	12:45 p.m.	5	8	Dormant; frozen rigid	2/15/27	41	9	18
Feb.15	1:05 p.m.	0	9	Dormant; frozen rigid	2/18/27	41	9	18
	5:30 p.m.	-5	10	Dormant; frozen rigid	2/18/27	21	29	58
	5:00 p.m.	-8	11	Dormant; frozen rigid	2/18/27	0	50	100

D. BREVICOMIS - TEST NO. 7

ACTIVITY OF HALF- TO FULL-GROWN LARVAE REMOVED FROM YELLOW PINE BARK WHEN EXPOSED TO AIR TEMPERATURES RANGING FROM 61 TO 42 DEGREES F.

Material collected at Northfork, Calif., December 1926. 450 larvae, removed from bark February 20 1927 were separated into 9 lots of 50 each and placed in open pasteboard containers. These were put in freezing compartment and temperature lowered at rate of 8 degrees per hour until larvae became dormant.

Date 1927	Hour	Temperature in box Fahr	Lot No. Removed	Condition of Larvae When Removed
2/21	2:15 p.m.	61	1	All active
	2:30 p.m.	57	2	All active
	2:45 p.m.	54	3	Less active
	3:00 p.m.	52	4	Less active
	3:15 p.m.	48	5	Sluggish; move if stimulated by brush
	3:40 p.m.	47	6	idem
	3:45 p.m.	45	7	idem
	4:00 p.m.	43	8	Sluggish; only slight movement when stim. by brush
	4:30 p.m.	42	9	Dormant; only slight movement when stim. by brush

Table No. 8

D. BREVICOMIS - TEST NO. 10

MORTALITY OF HALF- TO FULL-GROWN LARVAE
WHILE IN OVERWINTERING CONDITION IN YELLOW PINE BARK
SUBJECTED TO TEMPERATURES RANGING FROM 48 TO -20 DEGREES F.

Material collected at Northfork, Calif., in December 1927, and kept under field conditions, with temperatures ranging from 22 to 50 degrees, until test was started.

Date: 1928:	Hour	Temp.F. in Bark	Bark Section Removed:	Date of Cutting: Test	Dendroctonus brevicomis Larvae Alive:	Dead:	Mortality %
Jan.:			Check	1/18/27	114	4	33
18:	9:00 am	48					
	11:45 "	28					
	2:15 pm	19	1	1/19/27	97	3	3
	3:20 "	14	2	"	98	2	2.9
	4:20 "	10	3	1/20/27	97	3	3
	5:20 "	6	4	"	98	2	2
	6:15 "	-3	5	"	71	32	31
	9:00 "	-5	6	"	11	17	60.7
Jan.:	7:00 am	5					
19:	2:00 pm	-10	7			60	100
	3:00 "	-12					
	6:15 "	-13					
	7:45 "	-15	8			80	100
	10:00 "	-16					
Jan.:	6:00 am	-10					
20:	10:00 "	-15					
	6:00 pm	-20	9			98	100

Table No. 10

D. BREVICOMIS - TEST NO. 11

MORTALITY OF LARVAE WHILE IN ACTIVE DEVELOPING CONDITION IN YELLOW PINE BARK SUBJECTED TO TEMPERATURES RANGING FROM 60 TO -10° FAHR.

Material collected at Northfork, Calif., December 1927, when larvae were one-quarter to one-half grown. This material during January 1928 was kept in laboratory with temperatures ranging from 50 to 75-10° F. When test was started, February 7, brood had developed to full-grown larval stage.

Date 1928	Hour	Temp. in Bark	Bark Section Removed	Date of Cutting: Test	D. brevicomis larvae Alive	Dead	Mortality %	T. nigriventris Larvae Alive	Dead
Feb. 7	10:00 a.m.	60	0	check	220	4	1.7	1	
	1:00 p.m.	30							
	4:00 p.m.	22							
	4:50 p.m.	20	1	2/ 8/28	135	6	4	1	
	6:45 p.m.	15	2	"	140	4	2.5	1	
	8:10 p.m.	10	3	"	143	5	3	3	1
Feb. 8	5:30 a.m.	10							
	8:50 a.m.	5	4	2/10/28	125	3	2.3	1	
	10:20 a.m.	0	5	"	26	4	13		
	2:00 p.m.	-5	6	"	70	93	57		
	4:30 p.m.	-7	7	"		15	100		
	9:00 p.m.	-10	8	"		70	100		

Table No. 11

Table III

D. BREVICOMIS - TEST NO. 13

MORTALITY OF PUPAE IN YELLOW PINE BARK SUBJECTED TO TEMPERATURES RANGING FROM 65 TO -10° F.

Infested bark collected at Northfork, Calif., December 1927. Kept in laboratory for one month before freezing test was started, when about 80 per cent of brood had transformed to pupae.)

Date 1928	Hour	Temp. F. in Bark	Bark Section Removed	Date of Cutting Test	Dendroctonus brevicomis Larvae Alive	Larvae Dead	Pupae Alive	Pupae Dead	Mort. % Pupae	T. nigriventris Clerid Larvae Alive	Larvae Dead
Mar. 1	6:30 a.m.	65									
	3:00 p.m.	26	1	2/5/27	19		94		0	3	
	4:30 p.m.	21	2	"	24		80		0	2	
	7:15 p.m.	15	3	"	30		86		0		
	9:00 p.m.	11	4	"	17		84		0	2	
Mar. 2	3:00 a.m.	12									
	8:00 a.m.	6	5	"	22	8	84	16	15		9
	10:00 a.m.	0	6	2/6/27	12	8	75	27	26		9
	11:30 a.m.	-5	7	"		27	1	99	99		5
	3:00 p.m.	-8	8	"		15		122	100		2
	4:00 p.m.	-10	9	"		28		120	100		2

Table No. 13

Table IV

D. BREVICOMIS - TEST NO. 14

MORTALITY OF NEW ADULTS IN YELLOW PINE BARK SUBJECTED TO TEMPERATURES RANGING FROM 60 TO -10° F.

This material was collected at Northfork, Calif., December 1927, and kept under laboratory temperatures until majority of brood had transformed to adults and were ready to emerge.

Date 1928	Hour	Temp.F. in Bark	Bark Section Removed	Date of Cutting: Test	D.brevicomis Adults Alive	Dead	Mortality %
Mar.15	6:00 am	60					
	3:45 pm	20	1	3/20/28	90		0
	7:00 "	15	2	"	82	10	12
	9:00 "	10	3	"	7	70	90.9
Mar.14	2:30 am	12					
	7:00 "	5	4	"	2	73	97
	10:00 "	0	5	"	3	66	95.6
	1:00 pm	-5	6	"		48	100
	2:45 "	-10	7	"		68	100

Table No. 14

D. BREVICOMIS - TEST NO. 15

MORTALITY OF ADULTS AFTER EMERGENCE WHEN SUBJECTED TO AIR TEMPERATURES RANGING FROM 25 to 5° F.

80 active adults were separated into 4 lots of 20 each and placed in pasteboard containers, which were subjected to temperatures ranging from 25 to 5° F.

Date: 1923: Mar.:	Hour	Temp.F. in Container	Lot No.: Removed	Date of Examination	D. brevicomis Adults: Alive	Dead	Mort. %	Remarks
22:	2:15 pm:	25						
	3:10 "	20	1	3/23/23	20		0	
	3:45 "	15	2	"	20		0	
	5:00 "	10	3	"	18	2*	10	*2 adults show slight movements with antennae and legs when first removed; these died within a few days
	6:40 "	5	4	"		20*	100	*6 of these showed slight movements, as above, but died within a few days

Table No. 15

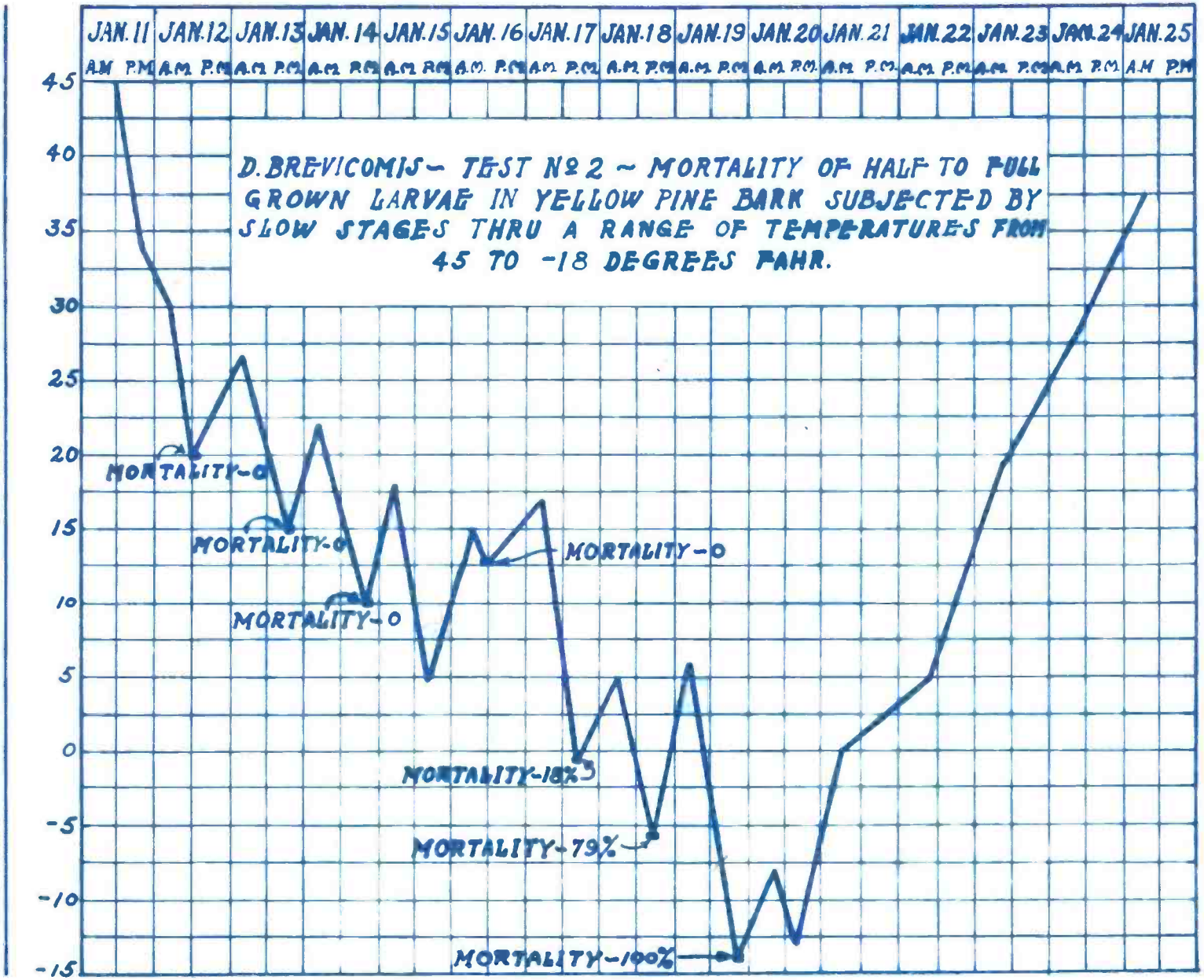
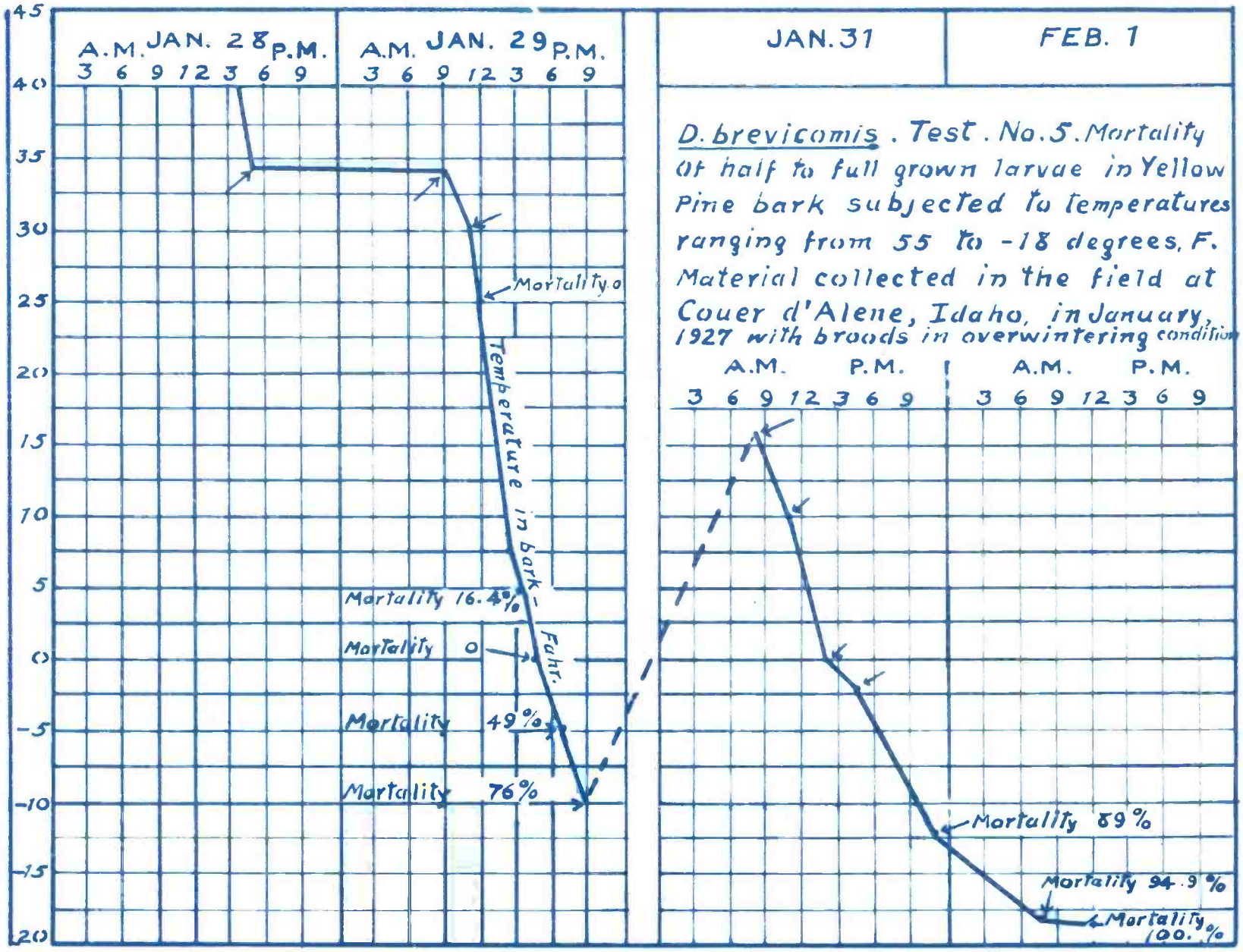

JAN. 11 A.M. P.M.
JAN. 12 A.M. P.M.
JAN. 13 A.M. P.M.
JAN. 14 A.M. P.M.
JAN. 15 A.M. P.M.
JAN. 16 A.M. P.M.
JAN. 17 A.M. P.M.
JAN. 18 A.M. P.M.
JAN. 19 A.M. P.M.
JAN. 20 A.M. P.M.
JAN. 21 A.M. P.M.
JAN. 22 A.M. P.M.
JAN. 23 A.M. P.M.
JAN. 24 A.M. P.M.
JAN. 25 A.M. P.M.
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
D. BREVICOMIS - TEST Nº 2 ~ MORTALITY OF HALF TO FULL GROWN LARVAE IN YELLOW PINE BARK SUBJECTED BY SLOW STAGES THRU A RANGE OF TEMPERATURES FROM 45 TO -18 DEGREES FAHR.
MORTALITY-0
MORTALITY-0
MORTALITY-0
MORTALITY-0
MORTALITY-18%
MORTALITY-79%
MORTALITY-100%

Chart No. 3



D. brevicomis. Test. No. 5. Mortality of half to full grown larvae in Yellow Pine bark subjected to temperatures ranging from 55 to -18 degrees, F. Material collected in the field at Couer d'Alene, Idaho, in January, 1927 with broods in overwintering condition

Chart No. 4

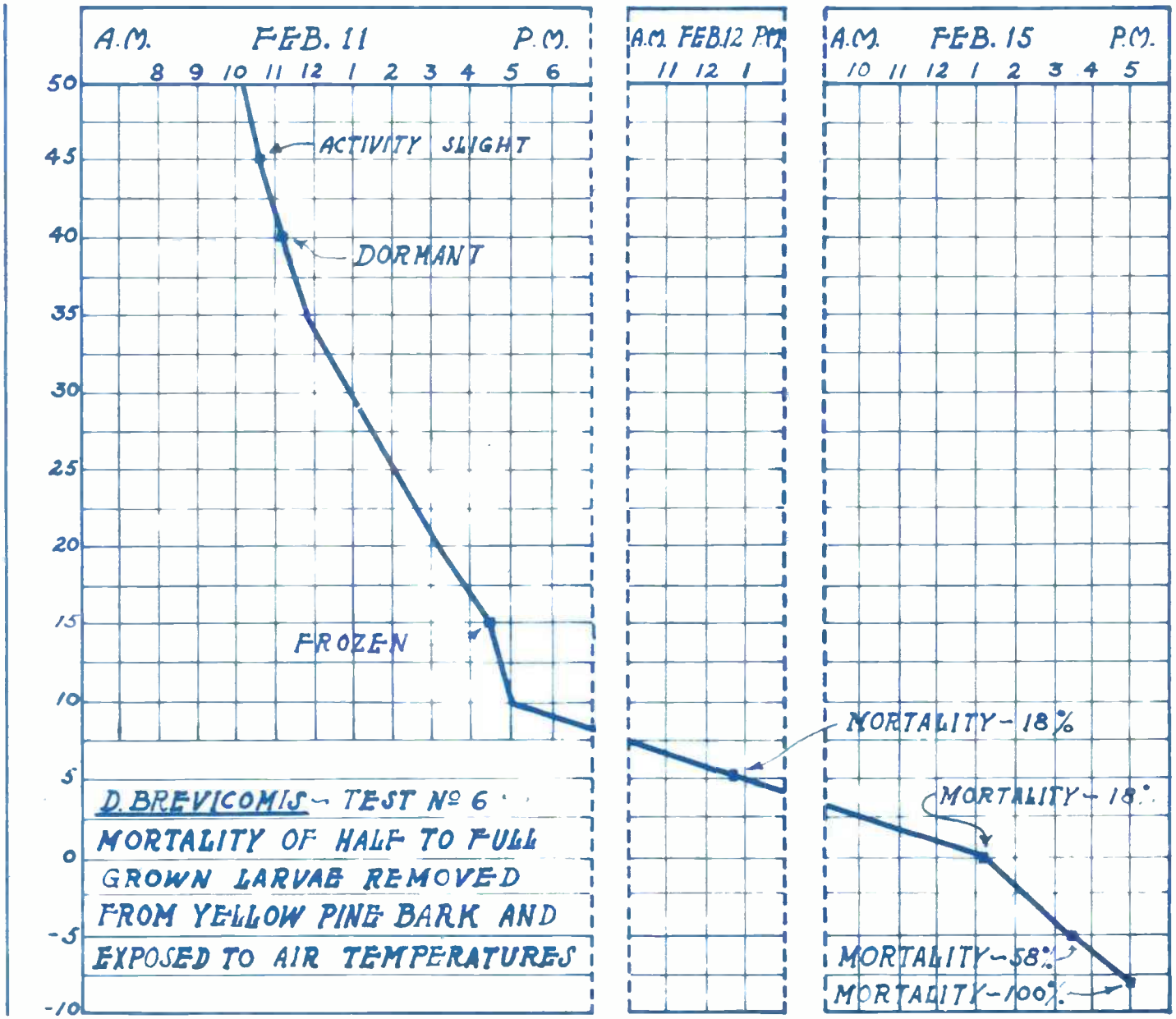

A.M. FEB. 11 P.M.
8 9 10 11 12 1 2 3 4 5 6
50
45
40
35
30
25
20
15
10
5
0
-5
-10
ACTIVITY SLIGHT
DORMANT
FROZEN
A.M. FEB.12 P.M.
11 12 1
A.M. FEB. 15 P.M.
10 11 12 1 2 3 4 5
MORTALITY - 18 %
MORTALITY - 18 %
MORTALITY - 58 %
MORTALITY - 100 %
D. BREVICOMIS - TEST Nº 6
MORTALITY OF HALF TO FULL
GROWN LARVAE REMOVED
FROM YELLOW PINE BARK AND
EXPOSED TO AIR TEMPERATURES

Chart No. 5

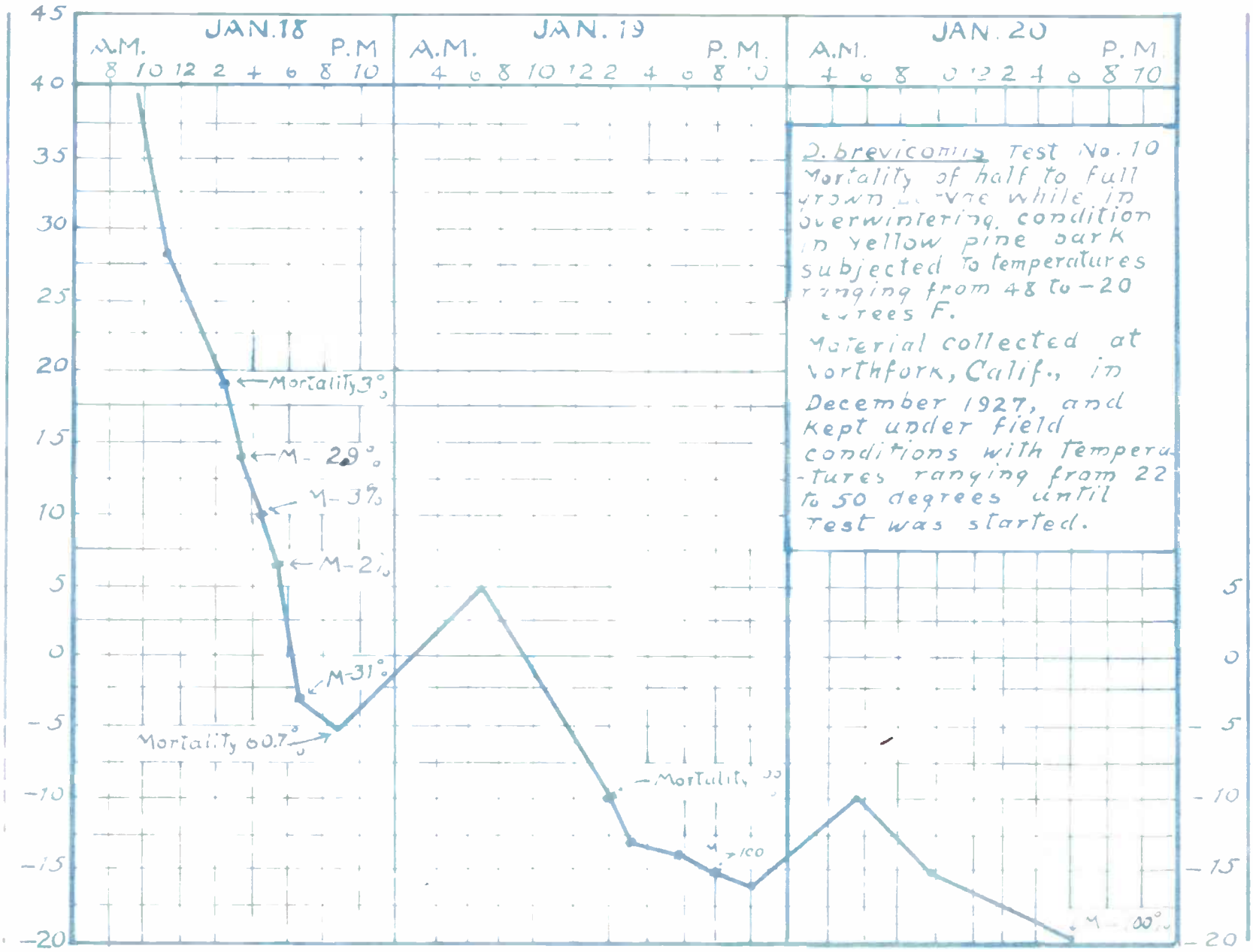

JAN. 18
JAN. 19
JAN. 20
A.M.
P.M.
8 10 12 2 4 6 8 10
4 6 8 10 12 2 4 6 8 10
4 6 8 10 12 2 4 6 8 10
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
-20
←Mortality 3%
←M- 2.9%
←M- 3%
←M-2%
←M-1%
Mortality 60.7%
—Mortality 33%
M-100%
M-100%
D. brevicomis Test No. 10
Mortality of half to full grown larvae while in overwintering condition in yellow pine bark subjected to temperatures ranging from 48 to -20 degrees F.
Material collected at Northfork, Calif., in December 1927, and kept under field conditions with temperatures ranging from 22 to 50 degrees until test was started.

Chart No. 7

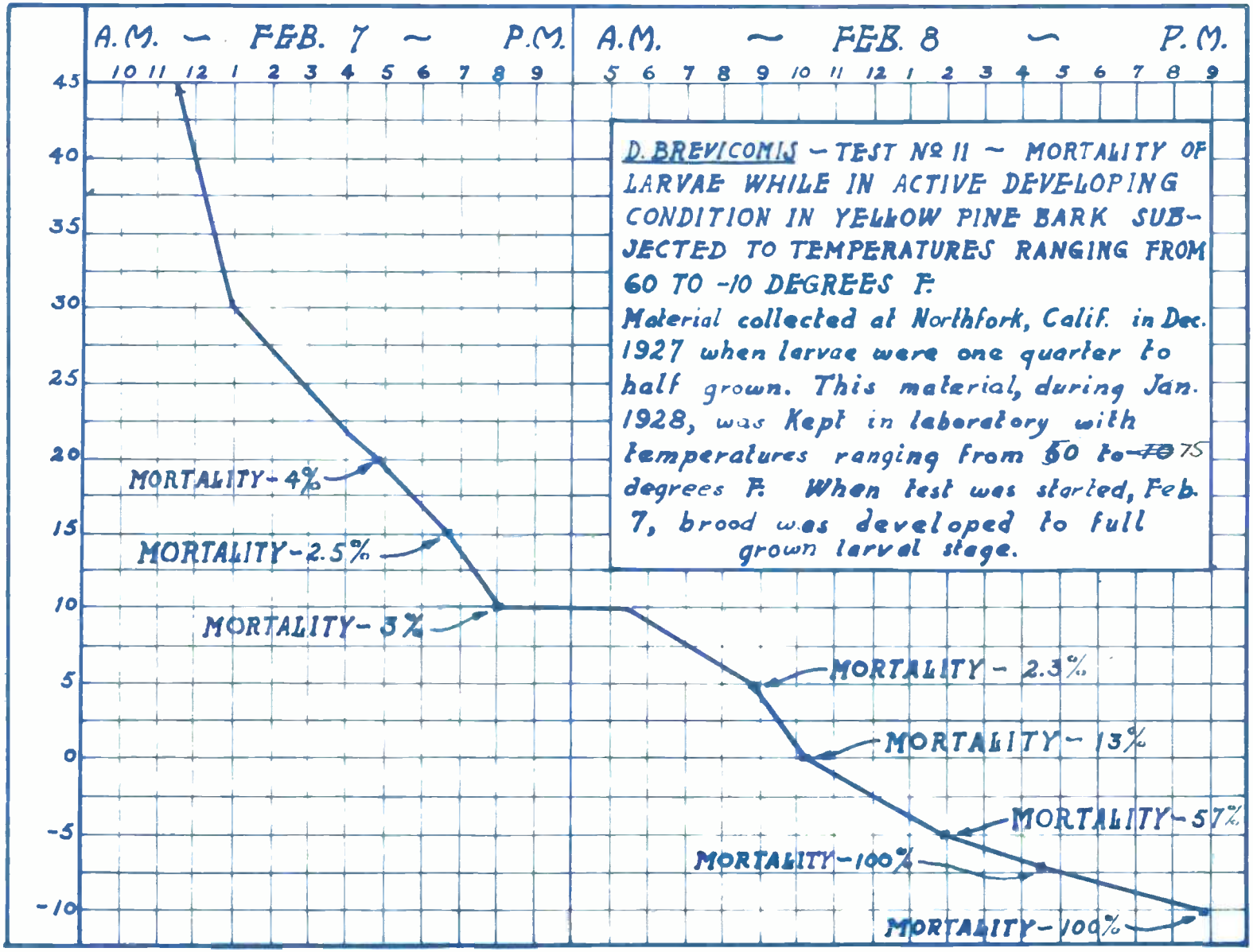

A.M. ~ FEB. 7 ~ P.M.
10 11 12 1 2 3 4 5 6 7 8 9
A.M. ~ FEB. 8 ~ P.M.
5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9
45
40
35
30
25
20
15
10
5
0
-5
-10
D. BREVICOMIS ~ TEST Nº 11 ~ MORTALITY OF LARVAE WHILE IN ACTIVE DEVELOPING CONDITION IN YELLOW PINE BARK SUBJECTED TO TEMPERATURES RANGING FROM 60 TO -10 DEGREES F.
Material collected at Northfork, Calif. in Dec. 1927 when larvae were one quarter to half grown. This material, during Jan. 1928, was kept in laboratory with temperatures ranging from 60 to ~~-10~~ 75 degrees F. When test was started, Feb. 7, brood was developed to full grown larval stage.
MORTALITY - 4%
MORTALITY - 2.5%
MORTALITY - 3%
MORTALITY - 2.3%
MORTALITY - 13%
MORTALITY - 57%
MORTALITY - 100%
MORTALITY - 100%

Chart No. 8

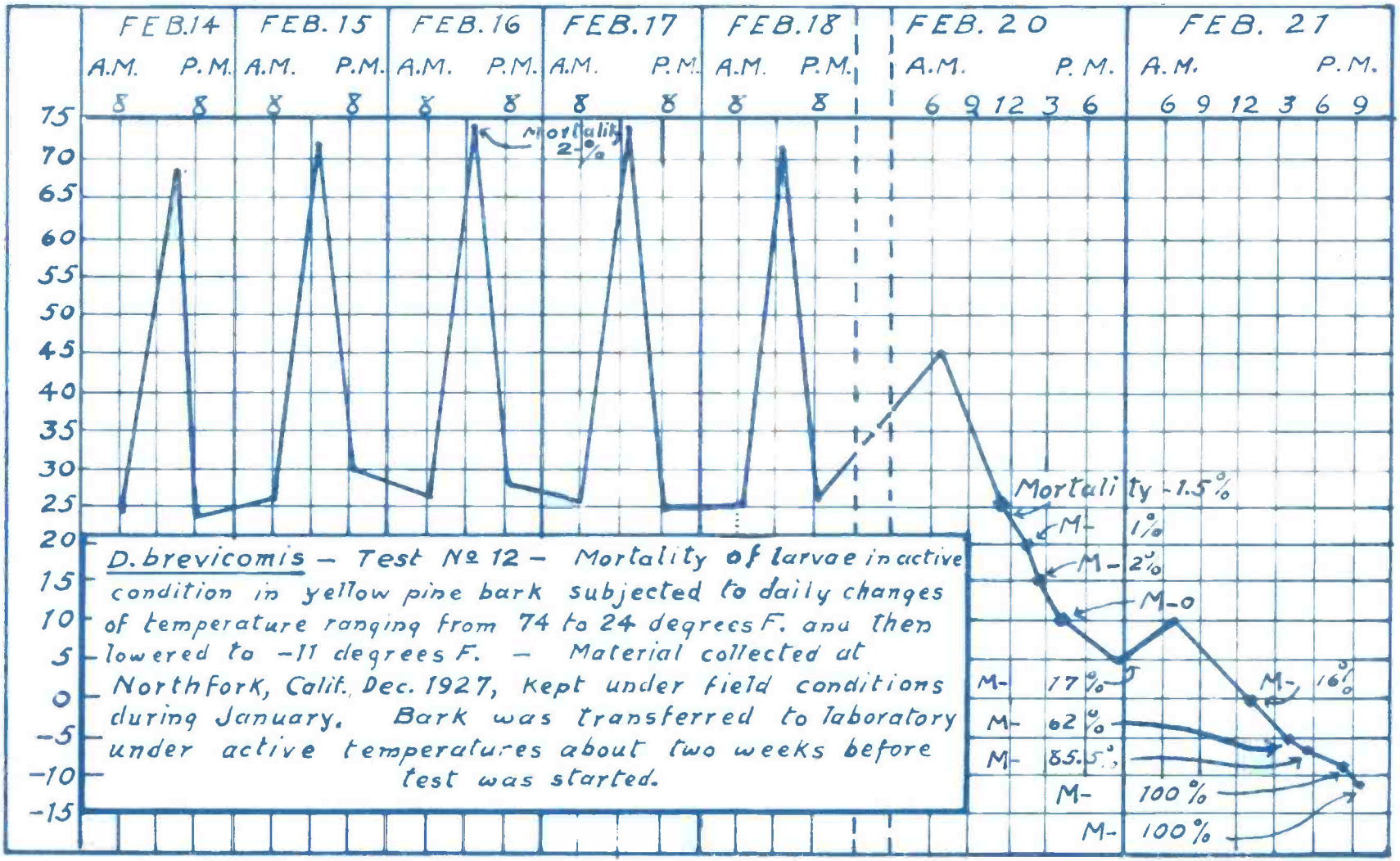

FEB.14
FEB. 15
FEB. 16
FEB. 17
FEB. 18
FEB. 20
FEB. 21
A.M.
P.M.
8
6 9 12 3 6
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
Mortality 2%
Mortality - 1.5%
M- 1%
M- 2%
M-0
M- 17%
M- 62%
M- 85.5%
M- 100%
M- 100%
M- 16%
D. brevicomis – Test № 12 – Mortality of larvae in active condition in yellow pine bark subjected to daily changes of temperature ranging from 74 to 24 degrees F. and then lowered to -11 degrees F. – Material collected at Northfork, Calif., Dec. 1927, kept under field conditions during January. Bark was transferred to laboratory under active temperatures about two weeks before test was started.

Chart No. 9

D. BREVICOMIS. TEST NO. 13. MORTALITY OF PUPAE IN YELLOW PINE BARK SUBJECTED TO TEMPERATURES RANGING FROM 65 TO -10 DEGREES F.

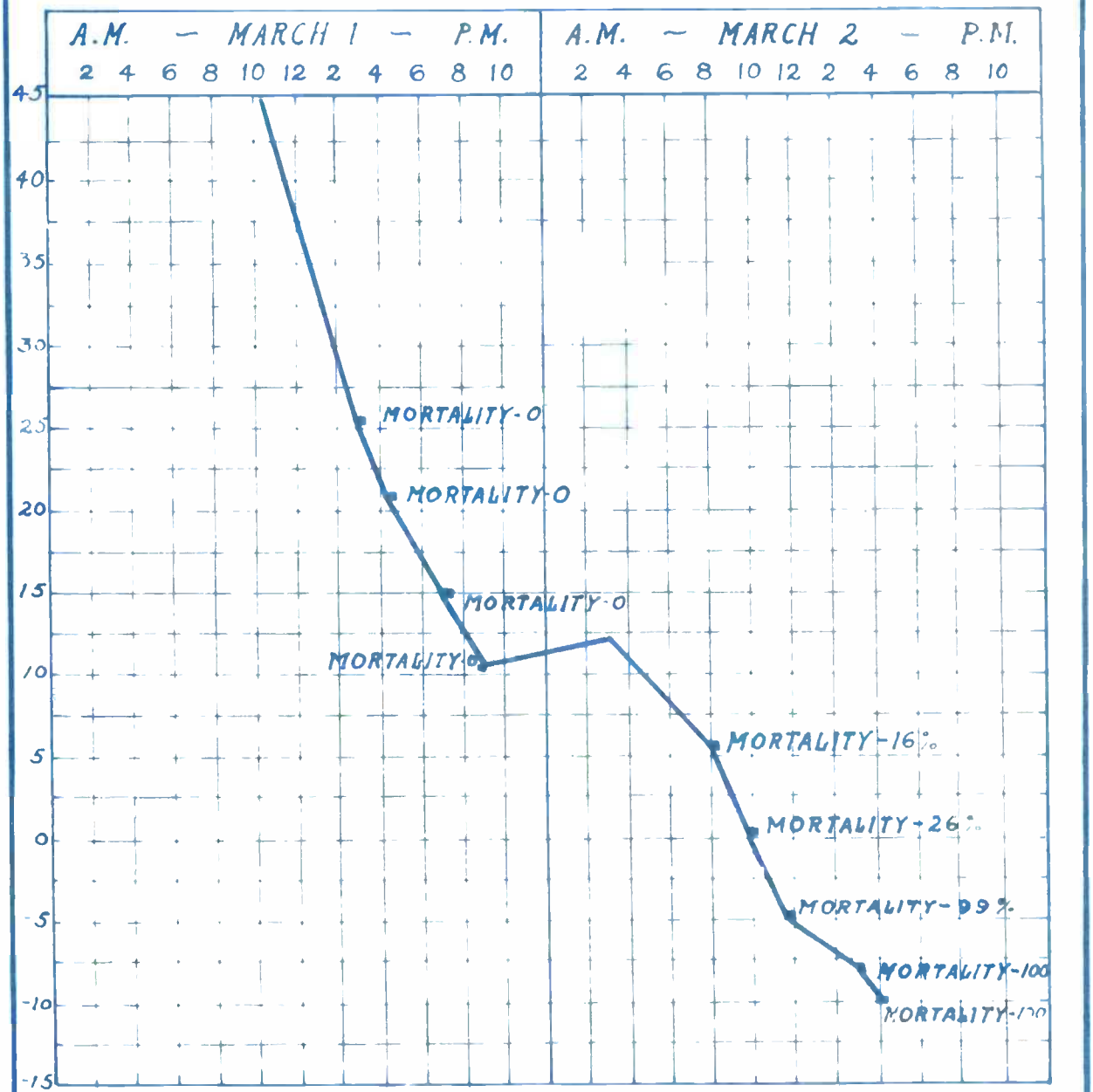
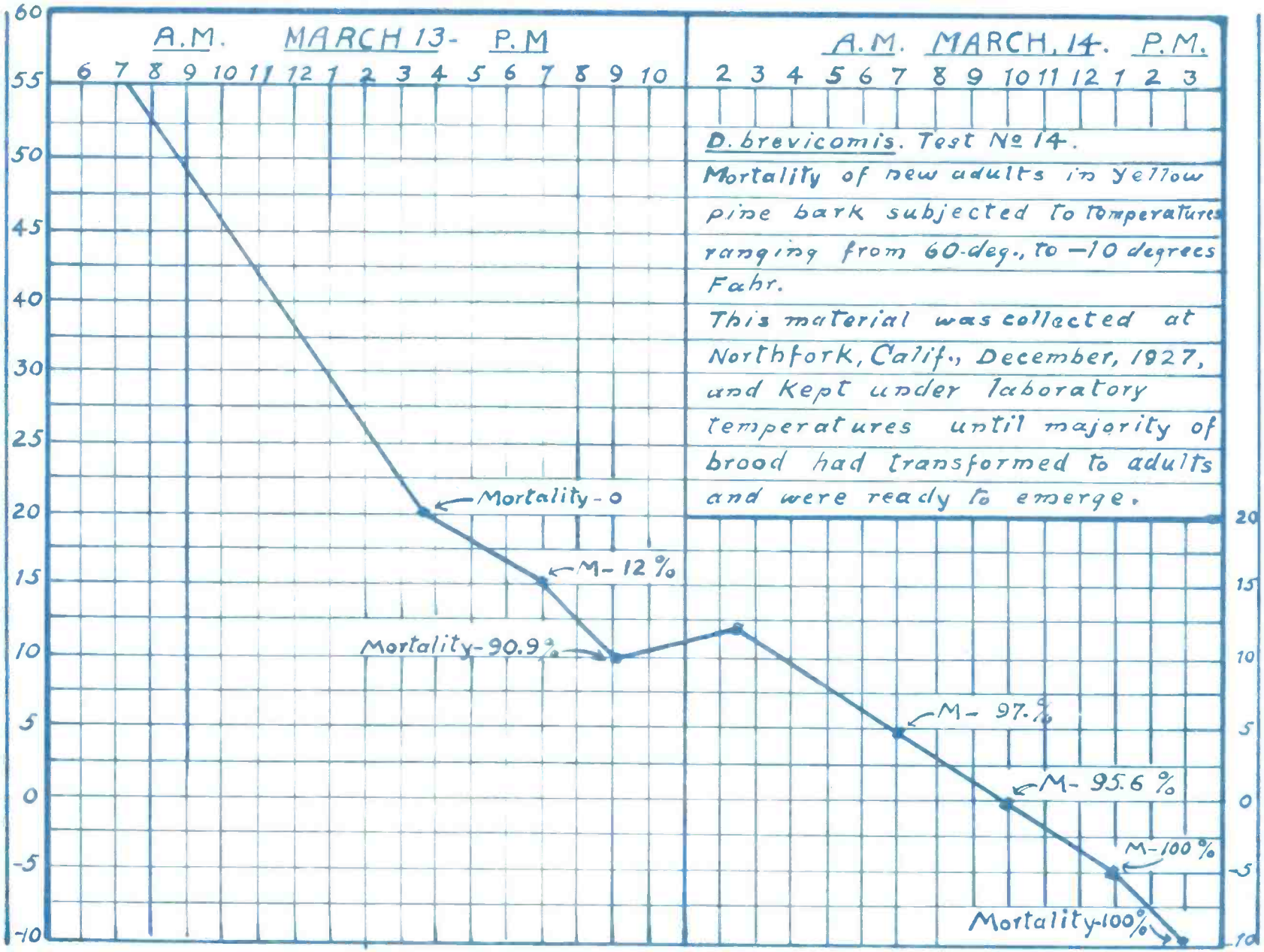


Chart No. 10



D. brevicomis. Test No 14.

Mortality of new adults in yellow pine bark subjected to temperatures ranging from 60-deg., to -10 degrees Fahr.

This material was collected at Northfork, Calif., December, 1927, and kept under laboratory temperatures until majority of brood had transformed to adults and were ready to emerge.

Chart No. 11

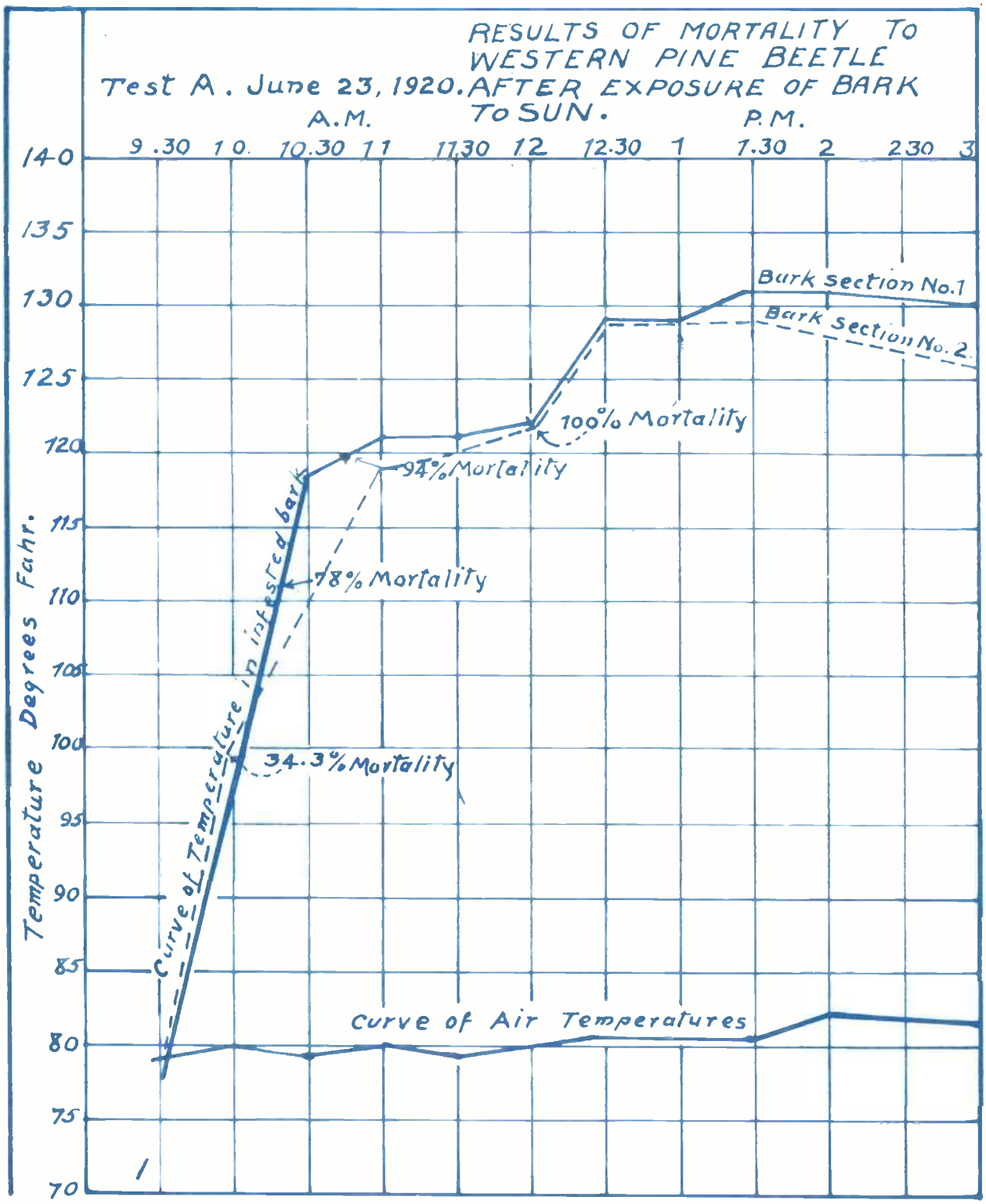

RESULTS OF MORTALITY TO WESTERN PINE BEETLE
Test A. June 23, 1920. AFTER EXPOSURE OF BARK TO SUN.
A.M.
P.M.
9.30 10. 10.30 11 11.30 12 12.30 1 1.30 2 2.30 3
140
135
130
125
120
115
110
105
100
95
90
85
80
75
70
Temperature Degrees Fahr.
Bark section No.1
Bark section No.2
100% Mortality
94% Mortality
78% Mortality
34.3% Mortality
Curve of Temperature in infested bark
Curve of Air Temperatures

Chart No. 12

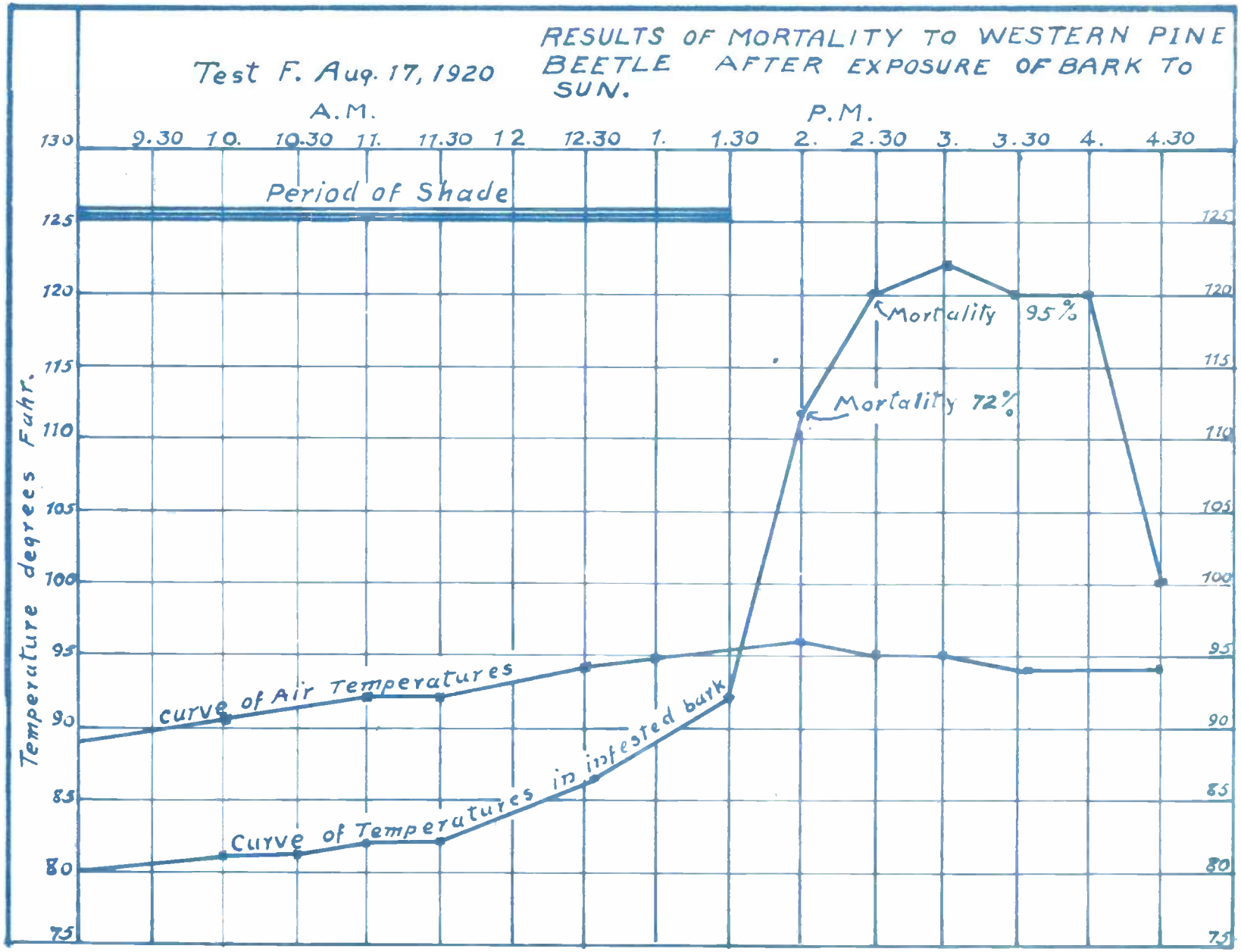
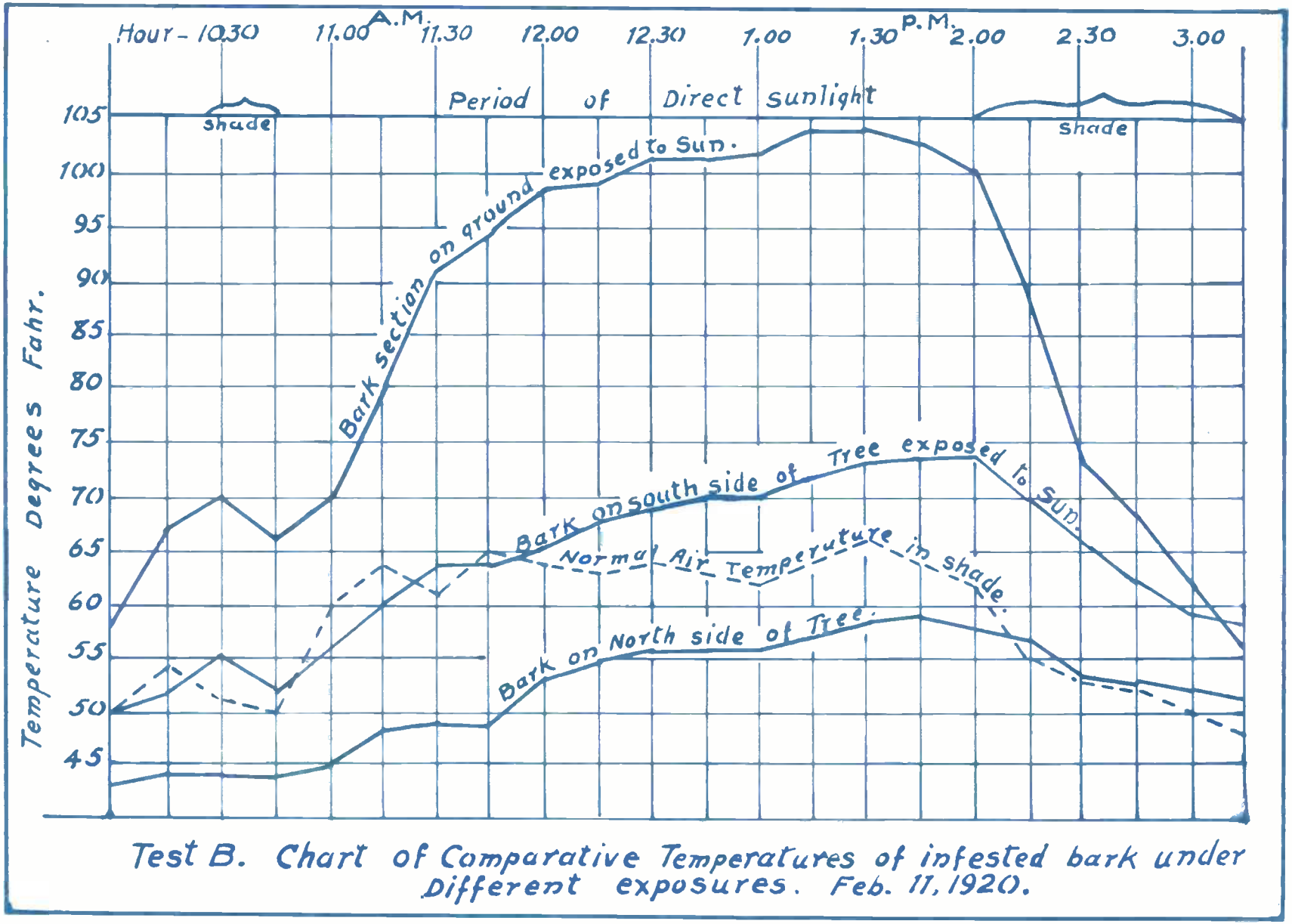

RESULTS OF MORTALITY TO WESTERN PINE BEETLE AFTER EXPOSURE OF BARK TO SUN.
Test F. Aug. 17, 1920
A.M.
P.M.
9.30 10. 10.30 11. 11.30 12 12.30 1. 1.30 2. 2.30 3. 3.30 4. 4.30
Period of Shade
Temperature degrees Fahr.
130 125 120 115 110 105 100 95 90 85 80 75
Mortality 95%
Mortality 72%
curve of Air Temperatures
Curve of Temperatures in infested bark

Chart No. 13



Test B. Chart of Comparative Temperatures of infested bark under Different exposures. Feb. 11, 1920.

Chart No. 14

Yellow pine bark section with mercurial thermometer imbedded to record temperature at depth of Western Pine Beetle broods.

a- Half to full grown Larvae in outer bark

b- Egg galleries in inner bark.

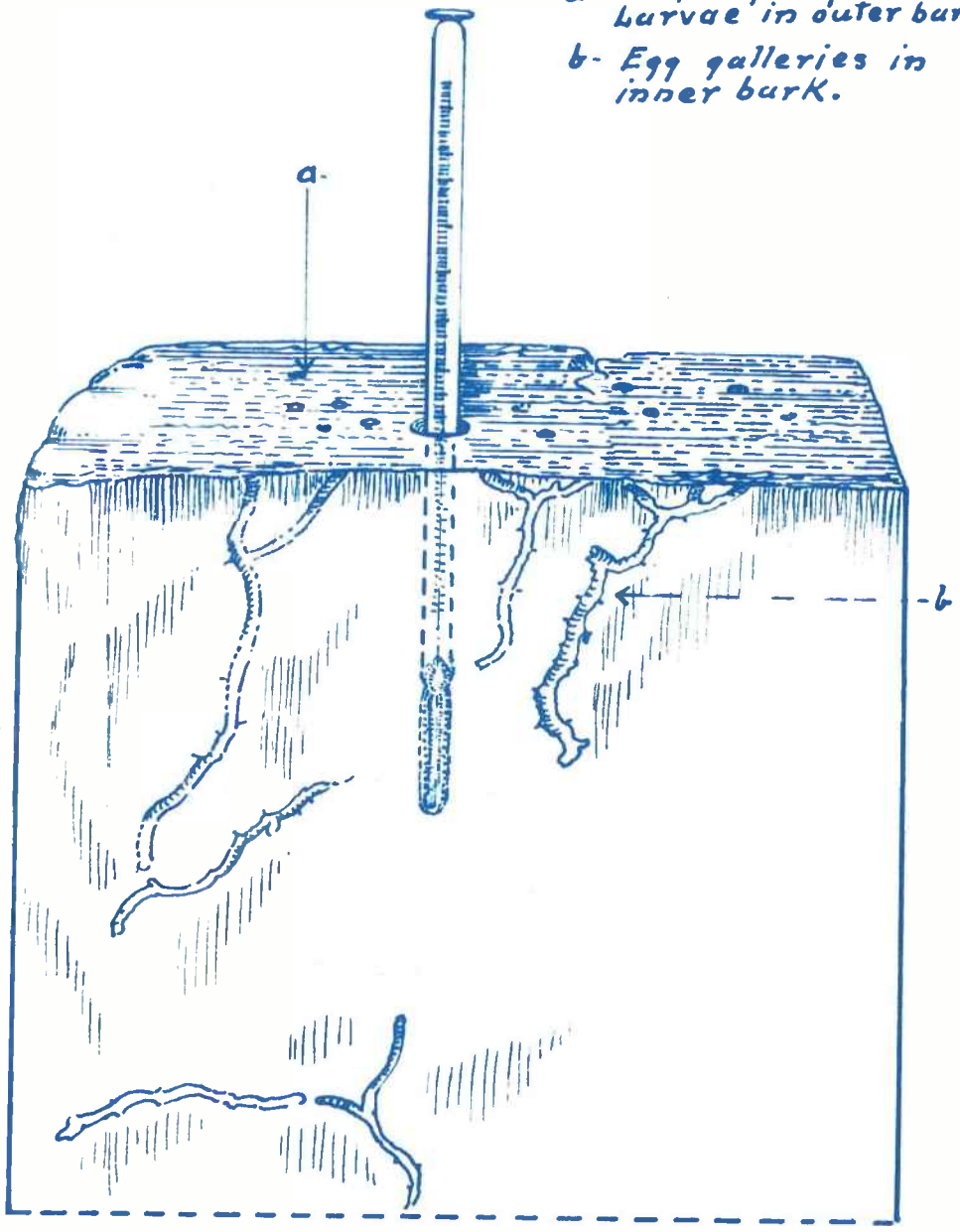


Chart No. 1

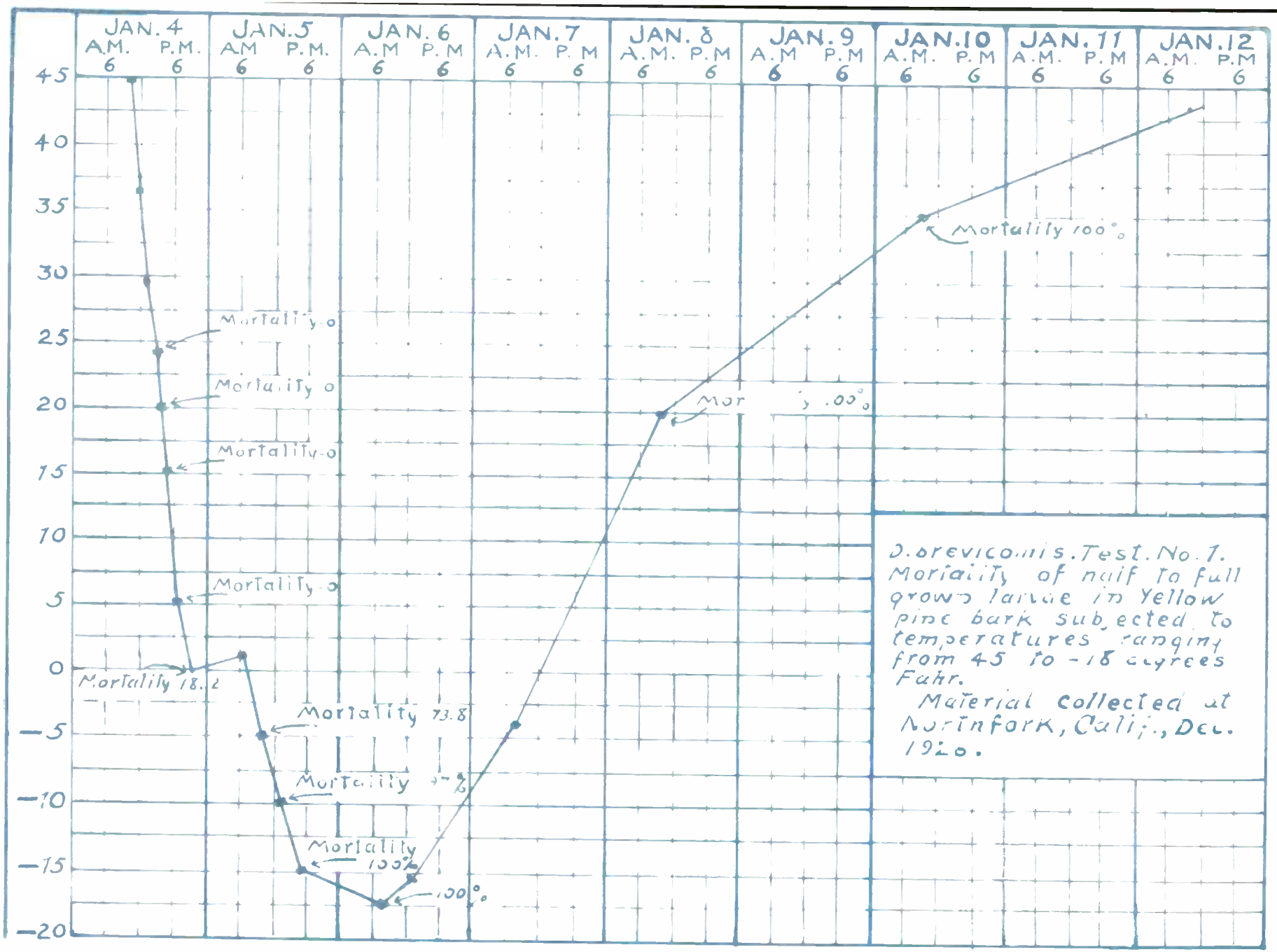

JAN. 4
JAN. 5
JAN. 6
JAN. 7
JAN. 8
JAN. 9
JAN. 10
JAN. 11
JAN. 12
A.M. P.M.
6 6
45
40
35
30
25
20
15
10
5
0
−5
−10
−15
−20
Mortality 0
Mortality 0
Mortality 0
Mortality 0
Mortality 18.2
Mortality 73.8
Mortality
Mortality 100%
100%
Mortality 100%
D. brevicomis. Test. No. 1. Mortality of half to full grown larvae in Yellow pine bark subjected to temperatures ranging from 45 to −18 degrees Fahr.
Material collected at Northfork, Calif., Dec. 1920.

Chart No. 2

TABLE II

EFFECTS OF LOW TEMPERATURES ON WESTERN PINE BEETLE LARVAE UNDER VARYING CONDITIONS OF EXPOSURE

(Overwintering larvae in yellow pine bark collected at Northfork, Calif.)

LOT I

Bark transferred from field and placed in cabinet after short period in laboratory; temperature lowered from 45° to -18° within 48 hours; test was started Jan. 4, 1928

Sec.No.	Time when removed from cabinet	Bark.temp. when removed	Date of Exam.	D.b.larvae: Alive	Dead	Mortality %
Check	Jan. 4 11:20 a.m.	46° F.	Jan. 7	185	0	0
No. 1	4 2:15 p.m.	25	5	23	0	0
2	4 3:25 "	20	5	11	0	0
3	4 4:30 "	15	5	43	0	0
4	4 6:00 "	10	6	135	0	0
5	4 7:45 "	5	6	27	0	0
6	4 9:45 "	0	6	148	33	18.2
7	5 10:45 a.m.	-5	6,18	53	150	73.8
7	5 12:45 p.m.	-10	6,18	7	248	97.
8	5 4:25 "	-15	6,19	0	168	100.
9	6 8:40 a.m.	-18	6,19	0	181	100.
10	8 4:00 p.m.	+26	19	0	97	100.

LOT II

Bark transferred from field and placed in cabinet after short period in laboratory; temperature lowered gradually from 45° to -15° within 216 hours; test started Jan. 11, 1928

Check	Jan.11 10:30 a.m.	48° F.	Jan.13	100	0	0
1	12 12:30 p.m.	20	13	100	0	0
2	13 4:25 "	15	20	103	0	0
3	14 4:30 "	10	20	85	0	0
4	15 2:45 "	5	21	165	0	0
5	17 4:30 "	-1	18	103	23	18
6	18 2:15 "	-5	19	34	133	79
7	no record					
8	19 8:30 "	-14	20		153	100
9	25 5:00 "	+39	27		203	100

LOT III

Bark transferred directly from field to cabinet with broods in dormant overwintering condition; temp. lowered from 48° to -15° in 48 hours

Check	Jan.18 9:00 a.m.	48° F.	Jan.18	114	4	3.3
1	18 2:15 p.m.	19	19	97	3	3.
2	3:20 "	14	19	99	3	2.9
3	4:20 "	10	20	97	3	3.
4	5:20 "	6	20	98	2	2.
5	6:15 "	-3	20	71	32	31.
6	9:00 "	-5	20	11	17	60.7
7	19 2:00 "	-10	20		60	100.
8	7:45 "	-15	20		80	100.
9	20 6:00 "	-20	21		98	100.

LOT IV

Bark transferred from field to laboratory and kept at 60-70° for 21 days; then transferred to freezing cabinet with larvae active and developing; temperature lowered from 60 to -15° in 48 hours

Check	Feb. 7 10:00 a.m.	60° F.	Feb. 7	220	4	1.7
1	4:50 p.m.	20	8	135	6	4.
2	6:45 "	15	8	140	4	2.5
3	8:10 "	10	8	143	5	3.
4	8 8:50 a.m.	4	10	125	3	2.3
5	10:20 "	0	10	26	4	13.
6	2:00 p.m.	-5	10	70	93	57.
7	4:30 "	-7	10		15	100.
8	9:00 "	-10	10		70	100.

LOT V

Bark transferred from field to laboratory and subjected to daily changes of temperature ranging from 45 to 25 to 70° for 6 days; then transferred to cabinet and lowered from 70 to -15° within 48 hours

		Bark Temp. Room	Bark Temp. Cabt.				
	Feb.14 8:30 a.m.		24				
	5:00 p.m.	68					
	8:30 "		23				
	15 8:30 a.m.		26				
	3:30 p.m.	72					
	8:30 "		30				
	16 8:30 a.m.		26				
Check	3:30 p.m.	74		Feb.16	340	7	2.
	8:30 "		28				
	17 8:30 a.m.		26				
	3:30 p.m.	74					
	8:30 "		25				
	18 8:30 a.m.		25				
	3:30 p.m.	72					
	8:30 "		26				
	20 7:00 a.m.		45				
1	11:30 "		25	23	126	2	1.5
2	1:45 p.m.		20	23	100	1	1
3	2:30 "		15	23	98	2	2
4	4:30 "		10	23	105		0
5	8:15 "		5	23	110	2	1.7
	21 7:00 a.m.		10				
6	1:30 p.m.		0	23	88	77	16
7	4:00 "		-5	23	46	75	62
8	5:30 "		-7	23	22	120	85.5
9	8:30 "		-9	23		100	100
10	9:40 "		-11	23		100	100

TABLE III

MORTALITY OF WESTERN PINE BEETLE PUPAE
RESULTING FROM LOW BARK TEMPERATURES

(Infested bark collected at Northfork, Calif., December 1927. Kept in laboratory month before freezing test was started, when about 80 per cent of brood had transformed to pupae.)

Sec. No.	Time from Cabinet	Bark Temp. when Removed	Date of Exam.	D.brevicomis Pupae Alive	D.brevicomis Pupae Dead	Mortality %
	1928					
1	Mar.1 3:00 pm	26°F.	Mar. 5,27	94		0
2	1 4:30 "	21	"	80		0
3	1 7:15 "	15	"	86		0
4	1 9:00 "	11	"	84		0
5	2 8:00 am	6	"	84	16	16.
6	2 10:00 "	0	Feb. 6,27	75	27	26.
7	2 11:30 "	-5	"	1	99	99.
8	2 3:00 pm	-8	"	0	122	100.
9	2 4:00 "	-10	"	0	120	100.

TABLE IV

MORTALITY OF D. BREV. NEW ADULTS RESULTING FROM LOW BARK TEMPERATURES

(This material was collected at Northfork, Calif., December 1927, and kept under laboratory temperatures until majority of brood had transformed to adults and were ready to emerge)

Sec. No.	Time from Cabinet	Bark Temp. when Removed	Date of Exam.	D.brevicomis: New Adults Alive	Dead	Mortality %
	1928					
1	Mar.13 5:45 pm	20°F.	Mar.20,28	90		0
2	13 7:00 "	15	"	82	10	12.
3	13 9:00 "	10	"	7	70	90.9
4	14 7:00 am	5	"	2	73	97.
5	14 10:00 "	0	"	3	66	95.6
6	14 1:00 pm	-5	"		48	100.
7	14 2:45 "	-10	"		68	100.

TABLE V

Mortality of Eggs of Western Pine Beetle Resulting from Low Temperatures in the Cambium

Sec. No.	Time When Removed from Cabinet	Temp. of Cambium wh. Removd	Date of Subsequent Exam.	No. Eggs Incubated	No. Eggs Failing to Incubate	Mortality %
1	May 23	50	Oct. 1, 1928	169	9	5.
2	24 9:30 am	15	"	54	3	5.
3	12:00 m.	10	"	48	9	15.
4	2:17 pm	5	"	45	26	36.6
5	4:30 pm	0	"	51	55	51.9
6	25 2:35 pm	-5	"	22	22	50.
7	26 9:45 am	-10	"	9	88	90.4
8	27 7:30 am	-15	"	11	76	87.3

11
76
87176.0 (87.3
696
640
609
310
251

TABLE VI

Mortality of Western Pine Beetle Larvae in Saturated Bark Compared with Dry Bark

Section No.	Time When Removed from Cabinet	Bark Temp. when Removed	Date of Exam.	D. brevicomis Larvae Alive	Dead	Mortality %
Dry Bark						
	1929					
Check	Jan. 14 1:00pm	50°F.	Jan. 14, 29	100	2	1.9
1	28 1:00 "	15	30, "	100	3	2.9
2	28 3:00 "	8	30, "	98	2	2.
3	29 2:30 "	5	31, "	90	10	10.
4	29 4:00 "	-1	31, "	85	15	15.
5	30 2:30 "	-4	Feb. 3, "	55	45	45.
6	31 5:05 "	-8	3, "		100	100.
Saturated Bark						
Check	Feb. 25 9:00am	50	25, "	112	2	1.7
1	26 8:00 "	24	28, "	117	1	.8
2	26 10:30 "	20	28, "	104	11	9.5
3	26 12:00 m	15	28, "	96	6	5.8
4	26 1:30pm	10	28, "	81	22	21.3
5	26 2:30 "	5	28, "	60	46	43.4
6	26 4:15 "	0	28, "	37	98	72.6
7	27 2:45 "	-5	28, "	5	100	95.2
8	27 4:15 "	-8	28, "		100	100.

TABLE VII

CONDITION AND MORTALITY OF HALF- TO FULL-GROWN LARVAE REMOVED FROM YELLOW PINE BARK AND EXPOSED TO AIR TEMPERATURES RANGING FROM 65 TO -8° F.

Material collected at Northfork, Calif., Dec., 1926; larvae removed from bark Feb. 10, 1927. 550 larvae were separated into 11 lots of 50 each and placed in open pasteboard containers. Temperature readings in freezing cabinet were taken with bulb of thermometer at same level as larvae in pasteboard containers. Condition of larvae at time of removal from cabinet was noted.

Sec. No.	Time When Removed from Cabinet 1927	Bark Temp. when Removed	Condition of Larvae When Removed	Date of Exam.	D. brevicomis: Larvae Alive	Larvae Dead	Mortality %
1	Feb. 11 9:10 am	65F.	Active	Feb. 15/27	50		0
2	11 10:35 "	45	Mostly active; few sluggish	"	49	1	2.
3	11 11:10 "	40	Dormant	"	50		0
4	11 11:45 "	35	"	"	50		0
5	11 3:15 pm	20	"	"	50		0
6	11 4:30 "	15	"	"	50		0
7	11 5:00 "	10	Dormant; frozen rigid	"	50		0
8	12 12:45 "	5	Dormant; frozen rigid	"	41	9	18.
9	15 1:05 "	0	Dormant; frozen rigid	Feb. 18/27	41	9	18.
10	15 3:30 "	-5	Dormant; frozen rigid	"	21	29	58.
11	15 5:00 "	-8	Dormant; frozen rigid	"	0	50	100.

TABLE VIII

MORTALITY OF HALF- TO FULL-GROWN D.BREV. LARVAE
IN YELLOW PINE BARK
SUBJECTED TO TEMPERATURES RANGING FROM 55 TO -18° F.

Bark collected at Coeur d'Alene, Idaho, January 1927, with broods in overwintering condition

Section No.	Time When Removed from Cabinet	Bark Temp. when Removed	Date of Exam.	D.brevicomis Larvae Alive	D.brevicomis Larvae Dead	Mortality %
	1927					
1	Jan.29 12:00 m	25°F.	Feb. 2,27	112		0
2	4:00 pm	4	"	61	12	16.4
3	5:00 "	0	Jan.31,27	119	0	0
4	7:00 "	-5	Feb. 1,27	25	23	49.
5	8:50 "	-10	Jan.31,27	25	81	76.
6	11:00 "	-12	Feb. 1,27	7	56	89.
7	Feb. 1 8:00 am	-18	" 2,27	11	207	94.9
8	10:25 "	-18	" 2,27		67	100.

Time	(a) Air Temp.	(b) Bark on north side of tree	(c) Bark on south side of tree	(d) Bark placed on ground in sun
10:00 am	50	43	50	58
10:15 "	54	44	52	67
10:30 "	51	44	56	70
10:45 "	50	44	52	66
11:00 "	60	45	56	70
11:15 "	63	48	60	82
11:30 "	61	49	64	91
11:45 "	65	49	64	94
12:00 m	64	53	65	98
12:15 pm	63	55	67	99
12:30 "	64	56	69	101
12:45 "	63	56	70	101
1:00 "	62	56	70	102
1:15 "	64	57	72	104
1:30 "	66	58	73	104
1:45 "	64	59	74	103
2:00 "	62	58	74	100
2:15 "	53	57	70	80
2:30 "	53	54	66	74
2:45 "	52	53	63	68
3:00 "	50	52	60	62
3:15 "	48	51	58	56

Table 9. EFFECT OF VARIOUS TEMPERATURES ON BROOD STAGES OF THE WESTERN PINE BEETLE IN THE OUTER BARK OF WESTERN YELLOW PINE

Temperature ° F.	Effect
-20	Fatal to all brood stages.
-15, -10, -8	Fatal to all brood stages; a low percentage of eggs and of of larvae which are adapted to severe winter climates may survive these temperatures.
-8, -5, 0, 5	Critical temperatures for larvae and pupae; mortality at 5° exceeds 50 per cent.
5, 10	Critical temperatures for adults; high mortality occurs at 10°; low mortality of larvae and pupae may occur at 5°.
10, 15	Larvae freeze, but recover if warmed back to active temperatures.
15, 20, 35, 40	Dormancy occurs in all brood stages.
40, 45	Larvae sluggish.
45, 55	Larvae and adults active.
55, 95	Maximum activity of larvae and adults.
95, 100	Larvae less active.
100, 105	Larvae sluggish.
105, 110	Paralysis of larvae after one or two hours' exposure; recovery possible if returned to lower temperatures.
110, 115	Paralysis of larvae after brief exposure; recovery possible if exposure is not prolonged.
115, 118	Paralysis of larvae after brief exposure (20 minutes), from which they do not recover.
120	Fatal to all brood stages.

Table VIII

RANGE OF BARK TEMPERATURES AFFECTING
BROOD STAGES OF THE WESTERN PINE BEETLE

TEMP. F

120
~~120~~ 118 } complete mortality of larvae, pupae and adults after brief exposures

115 } Complete mortality ~~fatal~~ after long exposures ; larvae do not recover from paralysis
110 } after 20 minutes exposure

105 } paralysis ~~of~~ of larvae occurs at 108 to 110: recovery possible if exposure is not prolonged; Some mortality results from prolonged exposures.

100 } larvae become sluggish showing slight activity;

95 - activity of larvae ~~slows down~~ decreases

90 }
} ~~period of~~ maximum activity of larvae
55 }

50 - activity of larvae decreases

45 }
40 } larvae become sluggish and apparent dormancy sets in

35 }
} dormancy occurs in all brood stages
20 }

15 }
10 } larvae become frozen but recover if warmed back to ~~active~~ temperatures
~~these tempaeraures are critical to adults and high mortality occurs at 10~~

5 } critical temperatures for adults; high mortality occurs at 10

0 }
- 5 } critical temperatures for larvae and pupae; mortality at -5 exceeds 75 60
percent ~~xxx5xxx~~ for ~~larvae~~ and 50 percent for egg stage.
- 8 }

-10 - fatal to all brood stages; (a ~~low~~ percent of larvae ~~adapted to severe~~ winterclimates) ~~may survive this point~~ ~~eggs may survive this point~~ and a low percent of survival of a low percent of the eggs and of larvae adapted to severe winter climates may occur
-15 " "

~~120~~ - Fatal to all brood stages,

TABLE IX

EFFECTS OF LOW TEMPERATURES ON WESTERN PINE BEETLE LARVAE UNDER VARYING CONDITIONS OF EXPOSURE

(Overwintering larvae in yellow pine bark collected at Northfork, Calif.)

LOT I

Bark transferred from field and placed in cabinet after short period in laboratory; temperature lowered from 45° to -18° within 48 hours; test was started Jan. 4, 1928

Sac.No.	Time when removed from cabinet	Bark.temp. when removed	Date of Exam.	D.b.larvae: Alive	Dead	Mortality %
Check	Jan. 4 11:20 a.m.	48° F.	Jan. 7	185	0	0
No. 1	4 2:15 p.m.	28	8	23	0	0
2	4 3:25 "	20	5	11	0	0
3	4 4:30 "	15	5	43	0	0
4	4 6:00 "	10	6	135	0	0
5	4 7:45 "	5	6	27	0	0
6	4 9:45 "	0	6	148	33	18.2
7	5 10:45 a.m.	-5	6,18	53	150	73.8
7	5 12:45 p.m.	-10	6,18	7	248	97.
8	5 4:25 "	-15	6,19	0	168	100.
9	6 8:40 a.m.	-18	6,19	0	181	100.
10	8 4:00 p.m.	-26	19	0	97	100.

LOT II

Bark transferred from field and placed in cabinet after short period in laboratory; temperature lowered gradually from 45° to -15° within 216 hours; test started Jan. 11, 1928

Check	Jan.11 10:30 a.m.	45° F.	Jan.13	100	0	0
1	12 12:30 p.m.	20	13	100	0	0
2	13 4:25 "	15	20	103	0	0
3	14 4:30 "	10	20	85	0	0
4	15 2:45 "	5	21	165	0	0
5	17 4:30 "	-1	18	103	23	18
6	18 2:15 "	-5	19	34	133	79
7	No record					
8	19 8:30 "	-14	20		153	100
9	25 5:00 "	+39	27		203	100

LOT III

Bark transferred directly from field to cabinet with broods in dormant overwintering condition; temp. lowered from 48° to -15° in 48 hours

Check	Jan.18 9:00 a.m.	48° F.	Jan.18	114	4	3.3
1	18 2:15 p.m.	19	19	97	3	3.
2	3:20 "	14	19	99	3	2.9
3	4:20 "	10	20	97	3	3.
4	5:20 "	6	20	98	2	2.
5	6:15 "	-3	20	71	32	31.
6	9:00 "	-5	20	11	17	60.7
7	19 2:00 "	-10	20		60	100.
8	7:45 "	-15	20		80	100.
9	20 6:00 "	-20	21		98	100.

LOT IV

Bark transferred from field to laboratory and kept at 60-70° for 21 days; then transferred to freezing cabinet with larvae active and developing; temperature lowered from 60 to -15° in 48 hours

Check	Feb. 7 10:00 a.m.	60° F.	Feb. 7	220	4	1.7
1	4:50 p.m.	20	8	135	6	4.
2	6:45 "	15	8	140	4	2.5
3	8:10 "	10	8	143	5	3.
4	8 8:50 a.m.	4	10	125	3	2.3
5	10:20 "	0	10	26	4	13.
6	2:00 p.m.	-4	10	70	93	57.
7	4:30 "	-7	10		15	100.
8	9:00 "	-10	10		70	100.

LOT V

Bark transferred from field to laboratory and subjected to daily changes of temperature ranging from 25 to 70° for 6 days; then transferred to cabinet and lowered from 70 to -15° within 48 hours

		Bark Temp. Room	Bark Temp. Cabt.				
	Feb.14 8:30 a.m.		24				
	5:00 p.m.	68					
	8:30 "		23				
	15 8:30 a.m.		26				
	3:30 p.m.	72					
	8:30 "		30				
	16 8:30 a.m.		26				
Check	3:30 p.m.	74		Feb.16	340	7	2.
	8:30 "		28				
	17 8:30 a.m.		26				
	3:30 p.m.	74					
	8:30 "		25				
	18 8:30 a.m.		25				
	3:30 p.m.	72					
	8:30 "		26				
	20 7:00 a.m.		45				
1	11:30 "		25	23	126	2	1.5
2	1:45 p.m.		20	23	100	1	1
3	2:30 "		15	23	98	2	2
4	4:30 "		10	23	105		0
5	8:15 "		5	23	110	2	1.7
	21 7:00 a.m.		10				
6	1:30 p.m.		0	23	88	77	16
7	4:00 "		-5	23	46	75	62
8	5:30 "		-7	23	22	120	85.5
9	8:30 "		-9	23		100	100
10	9:40 "		-11	23		100	100

TABLE II

EFFECTS OF LOW TEMPERATURES ON WESTERN PINE BEETLE LARVAE
UNDER VARYING CONDITIONS OF EXPOSURE
(Overwintering larvae in yellow pine bark collected at Northfork, Calif.)

LOT I

Bark transferred from field and placed in cabinet after short period in laboratory; temperature lowered from 45° to -18° within 42 hours; test was started Jan. 4, 1928

Spec.No.	Time when removed from cabinet	Bark temp. when removed	Date of Exam.	L.b.larvae: Alive:	Dead	Mortality %
Check	Jan. 4 11:20 a.m.	45° F.	Jan. 7	185	0	0
No. 1	4 2:15 p.m.	25	8	83	0	0
2	4 3:25 "	20	8	81	0	0
3	4 4:32 "	15	8	43	0	0
4	4 6:03 "	10	8	135	0	0
5	4 7:45 "	3	8	27	0	0
6	4 9:45 "	3	8	148	33	18.2
7	5 10:48 a.m.	-2	5,18	55	180	76.8
8	5 12:45 p.m.	-10	6,18	7	248	97.
9	5 4:25 "	-15	6,19	0	168	100.
0	6 8:40 a.m.	-18	6,19	0	181	100.
10	8 4:00 p.m.	+28	19	0	97	100.

LOT II

Bark transferred from field and placed in cabinet after short period in laboratory; temperature lowered gradually from 45° to -15° within 22.6 hours; test started Jan. 11; 1928

Check	Jan.11 10:30 a.m.	45° F.	Jan.13	109	0	0
1	12 12:30 p.m.	29	15	100	0	0
2	13 4:25 "	15	19	103	0	0
3	14 4:30 "	10	20	85	0	0
4	18 2:45 "	3	21	165	0	0
5	19 4:30 "	-1	19	103	23	22
6	18 2:15 "	-8	19	32	125	79
7	No record					
8	18 8:30 "	-14	20	153	100	
9	25 5:00 "	+30	27	203	100	

LOT III

Bark transferred directly from field to cabinet with broods in dormant overwintering condition; temp. lowered from 42° to -15° in 48 hours

Check	Jan.18 9:00 a.m.	45° F.	Jan.18	116	4	3.3
1	18 2:15 p.m.	39	19	87	3	3.
2	3:30 "	36	19	99	3	2.9
3	4:30 "	32	20	97	3	3.
4	5:30 "	6	20	68	2	3.
5	6:15 "	-3	20	71	32	31.
6	9:00 "	-5	20	11	17	60.7
7	19 2:00 "	-12	20		60	100.
8	7:45 "	-15	20		80	100.
9	20 8:00 "	-20	21		98	100.

LOT IV

Bark transferred from field to laboratory and kept at 60-70° for 22 days; then transferred to freezing cabinet with larvae active and developing; temperature lowered from 60 to -15° in 48 hours

Check	Feb. 7 10:00 a.m.	80° F.	Feb. 9	282	4	1.9
1	4:30 p.m.	20	8	135	6	4.
2	6:45 "	15	8	140	4	2.8
3	9:10 "	10	8	143	5	3.
4	8 8:50 a.m.	4	16	128	3	2.3
5	10:20 "	0	18	26	4	13.
6	2:00 p.m.	-5	19	99	88	57.
7	4:30 "	-9	19		19	100.
8	9:00 "	-19	19		70	100.

LOT V

Bark transferred from field to laboratory and subjected to daily changes of temperature ranging from 25 to 70° for 6 days; then transferred to cabinet and lowered from 70 to -15° within 42 hours

		Bark Temp. Room	Bark Temp. Cabt.				
	Feb.14 9:30 a.m.		24				
	5:00 p.m.	68					
	8:30 "		23				
	15 8:30 a.m.		26				
	3:30 p.m.	72					
	8:30 "		30				
	16 8:30 a.m.		28				
Check	3:30 p.m.	74		Feb.16	348	7	2.
	8:30 "		28				
	17 8:30 a.m.		26				
	3:30 p.m.	76					
	8:30 "		25				
	18 8:30 a.m.		25				
	3:30 p.m.	72					
	8:30 "		26				
	22 7:00 a.m.		42				
1	11:30 "		35	23	128	2	1.5
2	1:45 p.m.		30	23	100	1	1
3	2:30 "		18	23	98	2	2
4	4:30 "		10	23	106	1	0
5	8:19 "		5	23	110	5	1.7
	23 7:00 a.m.		30			5	
6	1:30 p.m.		0	23	98	77	18
7	4:00 "		-5	23	46	75	62
8	5:30 "		-7	23	22	180	88.5
9	8:30 "		-9	23		100	100
10	9:40 "		-11	23		100	100

TABLE III

MORTALITY OF WESTERN PINE BEETLE PUPAE RESULTING FROM LOW BARK TEMPERATURES

(Infested bark collected at Northfork, Calif., December 1927. Kept in laboratory month before freezing test was started, when about 80 per cent of brood had transformed to pupae.)

Sec. No.	Time from Cabinet	Removed	Bark Temp. when Removed	Date of Exam.	D. brevicomis: Pupae: Alive	Dead	Mortality %
	1928						
1	Mar. 1	3:00 pm	26°F.	Mar. 5,27	94		0
2	1	4:30 "	21	"	80		0
3	1	7:15 "	15	"	86		0
4	1	9:00 "	11	"	84		0
5	2	8:00 am	6	"	84	16	16.
6	2	10:00 "	0	Feb. 6,27	75	27	26.
7	2	11:30 "	-5	"	1	99	99.
8	2	3:00 pm	-8	"	0	122	100.
9	2	4:00 "	-10	"	0	120	100.

TABLE III

MORTALITY OF WESTERN PINE BEETLE PUPAE
RESULTING FROM LOW BARK TEMPERATURES

(Infested bark collected at Northfork, Calif., December 1927. Kept in laboratory month before freezing test was started, when about 80 per cent of brood had transformed to pupae.)

Sec. No.	Time from Cabinet	Bark Temp. when Removed	Date of Exam.	D.brevicomis Pupae Alive	D.brevicomis Pupae Dead	Mortality %
	1928					
1	Mar.1 3:00 pm	26°F.	Mar. 5,27	94		0
2	1 4:30 "	21	"	80		0
3	1 7:15 "	15	"	86		0
4	1 9:00 "	11	"	84		0
5	2 8:00 am	6	"	84	16	16.
6	2 10:00 "	0	Feb. 6,27	75	27	26.
7	2 11:30 "	-5	"	1	99	99.
8	2 3:00 pm	-8	"	0	122	100.
9	2 4:00 "	-10	"	0	120	100.

TABLE IV

MORTALITY OF D. BREV. NEW ADULTS RESULTING FROM LOW BARK TEMPERATURES

(This material was collected at Northfork, Calif., December 1927, and kept under laboratory temperatures until majority of brood had transformed to adults and were ready to emerge)

Sec. No.	Time from Cabinet	Bark Temp. when Removed	Date of Exam.	D.brevicomis: New Adults: Alive	Dead	Mortality %
	1928					
1	Mar.13 5:45 pm	20°F.	Mar.20,28	90		0
2	13 7:00 "	15	"	82	10	12.
3	13 9:00 "	10	"	7	70	90.9
4	14 7:00 am	5	"	2	73	97.
5	14 10:00 "	0	"	3	66	95.6
6	14 1:00 pm	-5	"		48	100.
7	14 2:45 "	-10	"		66	100.

TABLE IV

MORTALITY OF D. BREV. NEW ADULTS RESULTING FROM LOW BARK TEMPERATURES

(This material was collected at Northfork, Calif., December 1927, and kept under laboratory temperatures until majority of brood had transformed to adults and were ready to emerge)

Sec. No.	Time Removed from Cabinet 1928	Bark Temp. when Removed	Date of Exam.	D.brevicomis: New Adults: Alive	Dead	Mortality %
1	Mar.13 3:45 pm	20°F.	Mar.20,28	90		0
2	13 7:00 "	15	"	82	10	12.
3	13 9:00 "	10	"	7	70	90.9
4	14 7:00 am	5	"	2	73	97.
5	14 10:00 "	0	"	3	66	95.6
6	14 1:00 pm	-5	"		48	100.
7	14 2:45 "	-10	"		68	100.

TABLE V

Mortality of Eggs of Western Pine Beetle Resulting from Low Temperatures in the Cambium

Sec. No.	Time When Removed from Cabinet	Temp. of Cambium wh. Removd	Date of Subsequent Exam.	No. Eggs Incubated	No. Eggs Failing to Incubate	Mortality %
1	May 23	50	Oct. 1, 1928	169	9	5.
2	24 9:30 am	15	"	54	3	5.
3	12:00 m.	10	"	48	9	15.
4	2:17 pm	5	"	45	26	36.6
5	4:30 pm	0	"	51	55	51.9
6	25 2:35 pm	-5	"	22	22	50.
7	26 9:45 am	-10	"	9	88	90.4
8	27 7:30 am	-15	"	11	76	

TABLE V

Mortality of Eggs of Western Pine Beetle Resulting from Low Temperatures in the Cambium

Sec. No.	Time When Removed from Cabinet	Temp. of Cambium wh. Removd	Date of Subsequent Exam.	No. Eggs Incubated	No. Eggs Failing to Incubate	Mortality %
1	May 23	50	Oct. 1, 1928	169	9	5.
2	24 9:30 am	15	"	54	3	5.
3	12:00 m.	10	"	48	9	15.
4	2:17 pm	5	"	45	26	36.6
5	4:30 pm	0	"	51	55	51.9
6	25 2:35 pm	-5	"	22	22	50.
7	26 9:45 am	-10	"	9	88	90.4
8	27 7:30 am	-15	"	11	76	

TABLE VI

Mortality of Western Pine Beetle Larvae
in Saturated Bark Compared with Dry Bark

Section No.	Time When Removed from Cabinet	Bark Temp. when Removed	Date of Exam.	D. brevicomis Larvae Alive	D. brevicomis Larvae Dead	Mortality %
Dry Bark 1929						
Check	Jan. 14 1:00pm	50°F.	Jan. 14, 29	100	2	1.9
1	28 1:00 "	15	30, "	100	3	2.9
2	28 3:00 "	8	30, "	98	2	2.
3	29 2:30 "	5	31, "	90	10	10.
4	29 4:00 "	-1	31, "	85	15	15.
5	30 2:30 "	-4	Feb. 3, "	55	45	45.
6	31 5:05 "	-8	3, "		100	100.
Saturated Bark						
Check	Feb. 25 9:00am	50	25, "	112	2	1.7
1	26 8:00 "	24	28, "	117	1	.8
2	26 10:30 "	20	28, "	104	11	9.5
3	26 12:00 m	15	28, "	96	6	5.8
4	26 1:30pm	10	28, "	81	22	21.3
5	26 2:30 "	5	28, "	60	46	43.4
6	26 4:15 "	0	28, "	37	98	72.6
7	27 2:45 "	-5	28, "	5	100	95.2
8	27 4:15 "	-8	28, "		100	100.

TABLE VI

Mortality of Western Pine Beetle Larvae in Saturated Bark Compared with Dry Bark

Section No.	Time when Removed from Cabinet	Bark Temp. when Removed	Date of Exam.	D.brevicomis Larvae Alive	Dead	Mortality %
Dry Bark						
	1929					
Check	Jan.14 1:00pm	50°F.	Jan.14,29	100	2	1.9
1	28 1:00 "	15	30, "	100	3	2.9
2	28 3:00 "	8	30, "	98	2	2.
3	29 2:30 "	5	31, "	90	10	10.
4	29 4:00 "	-1	31, "	85	15	15.
5	30 2:30 "	-4	Feb. 3, "	55	45	45.
6	31 5:05 "	-8	3, "		100	100.
Saturated Bark						
Check	Feb.25 9:00am	50	25, "	112	2	1.7
1	26 8:00 "	24	28, "	117	1	.8
2	26 10:30 "	20	28, "	104	11	9.5
3	26 12:00 m	15	28, "	96	6	5.8
4	26 1:30pm	10	28, "	81	22	21.3
5	26 2:30 "	5	28, "	60	46	43.4
6	26 4:15 "	0	28, "	37	98	72.6
7	27 2:45 "	-5	28, "	5	100	95.2
8	27 4:15 "	-8	28, "		100	100.

TABLE VII

CONDITION AND MORTALITY OF HALF- TO FULL-GROWN LARVAE REMOVED FROM YELLOW PINE BARK AND EXPOSED TO AIR TEMPERATURES RANGING FROM 65 TO -8° F.

Material collected at Northfork, Calif., Dec., 1926; larvae removed from bark Feb. 10, 1927. 550 larvae were separated into 11 lots of 50 each and placed in open pasteboard containers. Temperature readings in freezing cabinet were taken with bulb of thermometer at same level as larvae in pasteboard containers. Condition of larvae at time of removal from cabinet was noted.

Sec. No.	Time When Removed from Cabinet 1927	Bark Temp. when Removed	Condition of Larvae When Removed	Date of Exam.	D. brevicomis Larvae Alive	D. brevicomis Larvae Dead	Mortality %
1	Feb. 11 9:10 am	65F.	Active	Feb. 15/27	50		0
2	11 10:35 "	45	Mostly active; few sluggish	"	49	1	2.
3	11 11:10 "	40	Dormant	"	50		0
4	11 11:45 "	35	"	"	50		0
5	11 3:15 pm	20	"	"	50		0
6	11 4:30 "	15	"	"	50		0
7	11 5:00 "	10	Dormant; frozen rigid	"	50		0
8	12 12:45 "	5	Dormant; frozen rigid	"	41	9	18.
9	15 1:05 "	0	Dormant; frozen rigid	Feb. 18/27	41	9	18.
10	15 3:30 "	-5	Dormant; frozen rigid	"	21	29	58.
11	15 5:00 "	-8	Dormant; frozen rigid	"	0	50	100.

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Material collected at Northfork, Calif., Dec., 1926; larvae removed from bark Feb. 10, 1927. 550 larvae were separated into 11 lots of 50 each and placed in open pasteboard containers. Temperature readings in freezing cabinet were taken with bulb of thermometer at same level as larvae in pasteboard containers. Condition of larvae at time of removal from cabinet was noted.

Sec. No.	Time When Removed from Cabinet 1927	Bark Temp. when Removed	Condition of Larvae When Removed	Date of Exam.	D. brevicomis Larvae Alive	D. brevicomis Larvae Dead	Mortality %
1	Feb. 11 9:10 am	65F.	Active	Feb. 15/27	50		0
2	11 10:35 "	45	Mostly active; few sluggish	"	49	1	2.
3	11 11:10 "	40	Dormant	"	50		0
4	11 11:45 "	35	"	"	50		0
5	11 3:15 pm	20	"	"	50		0
6	11 4:30 "	15	"	"	50		0
7	11 5:00 "	10	Dormant; frozen rigid	"	50		0
8	12 12:45 "	5	Dormant; frozen rigid	"	41	9	18.
9	15 1:05 "	0	Dormant; frozen rigid	Feb. 18/27	41	9	18.
10	15 3:30 "	-5	Dormant; frozen rigid	"	21	29	58.
11	15 5:00 "	-8	Dormant; frozen rigid	"	0	50	100.

TABLE VIII

MORTALITY OF HALF- TO FULL-GROWN D.BREV. LARVAE
IN YELLOW PINE BARK
SUBJECTED TO TEMPERATURES RANGING FROM 55 TO -18° F.

Bark collected at Coeur d'Alene, Idaho, January 1927, with broods in overwintering condition

Section No.	Time When Removed from Cabinet	Bark Temp. when Removed	Date of Exam.	D.brevicomis Larvae Alive	D.brevicomis Larvae Dead	Mortality %
	1927					
1	Jan.29 12:00 m	25°F.	Feb. 2,27	112		0
2	4:00 pm	4	"	61	12	16.4
3	5:00 "	0	Jan.31,27	119	0	0
4	7:00 "	-5	Feb. 1,27	25	23	49.
5	8:50 "	-10	Jan.31,27	25	81	76.
6	11:00 "	-12	Feb. 1,27	7	56	89.
7	Feb. 1 8:00 am	-18	" 2,27	11	207	94.9
8	10:25 "	-18	" 2,27		67	100.

TABLE VIII

MORTALITY OF HALF- TO FULL-GROWN D.BREV. LARVAE
IN YELLOW PINE BARK
SUBJECTED TO TEMPERATURES RANGING FROM 55 TO -18° F.

Bark collected at Coeur d'Alene, Idaho, January 1927, with broods in overwintering condition

Section No.	Time When Removed from Cabinet	Bark Temp. when Removed	Date of Exam.	D.brevicomis Larvae Alive	D.brevicomis Larvae Dead	Mortality %
	1927					
1	Jan.29 12:00 m	25°F.	Feb. 2,27	112		0
2	4:00 pm	4	"	61	12	16.4
3	5:00 "	0	Jan.31,27	119	0	0
4	7:00 "	-5	Feb. 1,27	25	23	49.
5	8:50 "	-10	Jan.31,27	25	81	76.
6	11:00 "	-12	Feb. 1,27	7	56	89.
7	Feb. 1 8:00 am	-18	" 2,27	11	207	94.9
8	10:25 "	-18	" 2,27		67	100.

SUMMARY

Brood stages of the western pine beetle show consistent susceptibility to temperatures that occur within the bark of yellow pine. Studies of the effect of certain temperatures have been conducted under both field and laboratory conditions which indicate the range of temperatures that result in maximum activity, dormancy and mortality.

Advanced larval stages in the outer bark do not survive an exposure of one hour at 118°F. Longer exposures at 115° will result in 100% mortality.

From 40% to 90% of the brood is killed by prolonged exposure to bark temperatures ranging from 100 to 115°.

Paralysis due to heat sets in after brief exposure to 108 to 110°; larvae may recover from this condition if exposures are not prolonged.

Activity becomes greatly diminished at temperatures from 95 to 105°.

Normal activity occurs between 50 and 95°.

Activity decreases below 50°. Dormancy due to cold sets in between 40 and 45°.

Between 10 and 15° larvae become rigidly frozen and take on a distinct white color, being found in this condition at all lower temperatures. When restored to normal temperatures they recover from this condition and resume activity unless killed by fatal temperatures, which occur around and below zero.

Mortality starts to occur around zero. The percentage of brood killed increases rapidly as temperatures are lowered below this point. A mortality of 50% or more can be expected at -5% and 100% at -10°.

Mortality within this range of critical temperatures was found to be consistent under varying conditions of exposure in material which had developed under the same regional influences. In material collected at Northfork, Calif., it was found that larvae developed complete mortality within the range between zero and -10°F. when the bark was lowered from normal to sub-zero temperatures under the following conditions:

1. Temperature lowered rapidly within a 48-hour period;

2. Temperature lowered gradually, extending over a 9-day period;

3. Temperature restored suddenly from sub-zero to normal (above 50°);

4. Temperature gradually warmed back to this normal through a period extending over several days;

5. Broods transferred directly from the field and exposed to low temperatures while in dormant overwintering condition;

6. Broods exposed to low temperatures while in active developing condition;

7. Broods exposed to low temperatures after period of six days, in which temperatures were raised to 70°F. during the day and lowered to 25°F. during the night.

In material from Coeur d'Alene, Idaho, where local air temperatures fall below zero during the winter months, mortality occurred within the same range between zero and -10°. However, a high percentage of survival occurred at these temperatures, and only 76% mortality developed at -10°. Complete mortality was recorded only at -18°.

Pupae are susceptible to somewhat higher temperatures than larvae. Complete mortality develops within the range from 5° to -6°.

New adults are susceptible to higher temperatures than either larvae or pupae. 90% mortality develops between 15 and 10°. No adults survive a temperature of -5°.

Records made at Coeur d'Alene indicate that in standing infested trees bark temperatures do not go as low as the minimum air temperatures. In the case recorded minimum bark temperatures were 10° and 12° higher than minimum air temperatures. This dispersion was sufficient to prevent exposure of broods to critical sub-zero temperatures.

Insufficient records indicate that predators are killed at temperatures somewhat higher than those fatal to the western pine beetle. Parasitic larvae, however, were not killed by the temperatures as low as -20°F. experienced in the tests.

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6. Broods exposed to low temperatures while in active developing condition;

7. Broods exposed to low temperatures after period of six days, in which temperatures were raised to 70°F. during the day and lowered to 25°F. during the night.

In material from Coeur d'Alene, Idaho, where local air temperatures fall below zero during the winter months, mortality occurred within the same range between zero and -10°. However, a high percentage of survival occurred at these temperatures, and only 76% mortality developed at -10°. Complete mortality was recorded only at -18°.

Pupae are susceptible to somewhat higher temperatures than larvae. Complete mortality develops within the range from 5° to -6°.

New adults are susceptible to higher temperatures than either larvae or pupae. 90% mortality develops between 15 and 10°. No adults survive a temperature of -5°.

Records made at Coeur d'Alene indicate that in standing infested trees bark temperatures do not go as low as the minimum air temperatures. In the case recorded minimum bark temperatures were 10° and 12° higher than minimum air temperatures. This dispersion was sufficient to prevent exposure of broods to critical sub-zero temperatures.

Insufficient records indicate that predators are killed at temperatures somewhat higher than those fatal to the western pine beetle. Parasitic larvae, however, were not killed by the temperatures as low as -20°F. experienced in the tests.